TECHNICAL CREATION AS A WHOLE, IN ENGINEER TRAINING

G. Jándy

Department of Building Management and Organization,
Technical University, H-1521 Budapest

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Abstract

Technical interventions, creative works (products) become in our days more and more complicated and complex, their far-reaching influences and consequences last for a long time, and all these require new scientific and institutionalized methods. This will have to take on a more and more definite character in engineering education.

Complex engineering products generally consist of cooperative subsystems and heterogeneous component parts going back to different specialities and industrial branches. Therefore there is a need for engineers who are capable of surveying the various influences and consequences of technical innovations and its inner and outer interactions.

Main differences in the structure of education can be recognized in engineer training in various social systems as well as in different countries. There are differences in the extent of natural science foundation and its place in the curriculum, in the degree of specialization within graduate training, the proportion of knowledge of economic and management and their place in the curriculum, as well as in the fact whether the interdependences in the entire process of engineering interventions and of innovations, and their social, economic, ecologic, etc., interactions are treated within the framework of graduate training and how they are discussed. Engineering products and projects, but even the simpler tools and apparatuses have to meet certain aesthetic requirements besides their utility functions. Thus, e.g., as it is wellknown, structures have to merge into their built and natural environment. The production runs always with waste matter and rubbish, too, which often have polluting, sometimes even toxic influence on the environment. Construction is generally accompanied by lesser or greater destruction. Producers and building contractors have to prevent these harmful effects and consequences, or they have to put an end to them; they have to find solutions which spare the health, and the natural, built, as well as aesthetic environment. The only way engineers responsible for the success and future of the product can ensure the fulfilment of these various functions, is to be aware of the legal, physiological, sociological, psychological, and aesthetic problems related to the use and success of the product, beyond the necessary knowledge of natural science and technology, as beyond a direct knowledge concerning the structure and inner processes of the product. It is open to discussion to what extent secondary education prepares students for this task, and how much of this foundation through social sciences is left to the university.

Differences are still greater in postgraduate training, in the scientific standard of doctor's theses, etc., to say nothing of the differences in the contents of the very same subjects, and in the pedagogics, in training requirements and efficiency, and of the human factors. In the cause of renewal and improvement of the engineer training the time-horizon of the social foresight should be pushed from tomorrow to 15—20 years forward.

In our age *technical interventions* and *products* become more and more complicated and complex, their far-reaching (useful and harmful) influences and consequences last for a long time, and are on the increase. Perplexing problems are raised *due to the inherences and interactions* of their development, execution, introduction, operation, maintenance, future, success, possible further development, and some time their termination. All these require new scientific and insitutionalized methods, and this will have to take on a more and more definite character in engineering education as well.

Complex engineering products generally consist of cooperative subsystems and heterogeneous component parts going back to different specialities and industries; specialists and working organizations in various subordinations, and companies bound by contracts, take part in their development arranged in time and space, relying on various devices and scientific disciplines.

Subsequent to the historical development of the division of labour in industry that started in the Renaissance, it is only our century that has brought about really quick specialization in engineering activities. In XVIth century creative intellectuals were expected to possess comprehensive knowledge, imagination and skill. It is sure that the very narrow, more and more isolated specialization characterizing our days has been a prerequisite of the technical development of our century. The evolution of electrical engineering education is a very good example of this phenomenon. However, the danger is recognizable already, that this tendency, namely that engineering education is becoming more and more specialized by narrowing the scope of studies and emphasizing the details, turn into one of the strongest barrier to further technical development. It is exactly these difficulties that can recently be experienced in the development and general use of computer-aided flexible production systems. One of the greatest obstacles to quicker technical development is the contradiction between the historically established *fragmentation* of skills, disciplines, national and corporate ambitions, abilities, incentives, and approaches and the *integration* which has become decisively important by now. Producing organizations have been fragmented within themselves, and motivation is not coherent either. The traditional fields of activities of professional branches and sections have been established, and all of them believe that they are interested in isolation, self-expansion and the monopolization of some particular functions.

The structure of our engineering education is no exception to this tendency, either.

The main types of careers open to engineers are *the design of engineering structures* and their *realization* in accordance with the plans, i.e., their production or implementation. As a rule, it is technical designing that is traditionally in the centre of *engineering education*, and it is wellknown that this requires thorough theoretical training and efforts of a whole individual. The position of production and implementation in this education are enforced by the development of technology, the increasing complexity of organizations carrying it into effect, the prosperity of computer science, and the requirements of intensive development of national economy. It is entirely reasonable to require that engineers working in the field of production, realization, should also be familiar with the characteristic products of a technical field, their function and constructions, and fundamental methods of their designing, but they also have to be prepared for the particular problems of *the technology and organizational forms of implementation, and of management* in the framework of their graduate training; they have to get acquainted with the devices and methods of the latter, too. Besides the above-mentioned two types of careers, a lot of engineers work in research and development, as well as in marketing or in public administration.

If engineering activities are examined from another aspect, it can also be said that engineers always function as part of management services (institutionalized management) in the hierarchy of management. Exaggeratedly, this is also true, if engineers participate in technical designing proper (construction), or in research, as there is no denying it that the planning, organization, and control of industrial production and servicing processes, the preparation of control of these processes in particular, require special technical skill. Several functions of institutionalized management are incumbent upon economists and lawyers to perform. There are a great number of these managemental functions for which several professions have to share responsibility. But it is first of all technical intellectuels that have to cope with the problems of *planning and controlling* production, implementation, as well as research-development and technical designing processes, the problems of work and plant organization, those of lay-out of working sites and of securing the devices, as well as of production control in industrial, building industrial, transportational, and servicing enterprises.

Beside justification for narrow specialization also such engineers are needed whose strong point is a wide largeness of view, a capability for the synthesis and for seeking harmony in the production process. But against such *generalist* education there has always been a logical argument the danger of shallowness in professional knowledge. However, this danger can very efficiently be warded off nowadays by computerized information systems, by expert systems. Consequently, the most important problem is no longer that a generalist cannot be informed well enough of various professional questions, but that there are very few engineers capable of surveying technical innovations as having various influences and consequences, inner and outer interactions, thus, e.g., who are capable of grasping the whole of flexible production systems, of holistic, as well as methodical and scientific approach in designing and implementation. Therefore there is a real great need for engineers; — who are well-trained in the fundamentals of technical sciences, especially in physics and mathematics; — who can cope with unexpected problems and requirements, too; — who are receptive to human ambitions, as well as social sciences and humanities (including history, sociology, economy, ecology, and aesthetics); — moreover, who have had the opportunity to gain experience at workshop, design, trade, and management levels in a variety of situations in practice; — and who are well-trained in the utilization of computer systems, both in the development and implementation of technical products and in the operation of complex technical equipment and networks, as well as in the management of organizations including these systems.

It is obvious that we are in need of a comprehensive *guiding principle*, of a "script" of the complex activities involved in technical production, when the task is, e.g. to develop, establish, and operate a telecommunication network, a computer data network, the automated traffic control of a junction, or even a hospital or a hydroelectric power station, perhaps the coordinated maintenance of a settlement's life and health. It is a novel task, more complex than the foregoing to bring the complex processes and the necessary production factors into qualitative and quantitative harmony in the modern production systems, and to maintain their dynamic equilibrium state.

In our age a reason why the systems engineering has come into being was to bring nearer to one another research-development, and the design of a structure, as well as its production, implementation, utilization, respectively marketing. This warns us that it is vital that researchers and designers pay attention to interrelationships between phenomena—as functions, requirements, structures, consequences, etc. This is how *project management* has come into being—besides production management—within the framework of systems engineering. Project management helps the more efficient accomplishment of industrial resp. technical *innovations* and single *projects* of complex structure, to be carried out with the given means and within a predetermined period.

Systems engineering has generally been regarded as a branch of science that deals with the laws of the whole process of technical creation and with those of its internal and external interactions, with the analysis of situation of the establishment (i.e. development and implementation), maintenance, and further development of the new objective system, with the planning and control of its complex processes, with the complex estimation of the result extended over its planned life-time, as well as with the connected methodology of all these problems. This interpretation of systems engineering largely corresponds to that accepted by the Systems Engineering Committee of the Hungarian Academy of Sciences, too. We believe that — within this framework of systems engineering — *the general theory of* research and development as well as *technical designing* (or system design) is taking shape, first on the level of certain engineering professions only, then, proceeding towards more complex levels, universally as well. Several successful attempts have been made to introduce a subject like systems engineering, among others in engineering education in Hungary, too.

The teaching of systems engineering has another trend, too, where more emphasis is laid on *methods* which *help the process of technical creation* but are not built into the traditional special subjects on designing and controlling of the objects (constructions, products, projects). In this connection we mostly consider methods of which, for the time being, only the theoretical foundations are represented in the basic curriculum of mathematics, mechanics, and computer science, or methods which are based on knowledge being not at all general, or only little accepted in engineering education (such as, e.g. statistics, economics, law, sociology, psychology, aesthetics, at certain universities), or which are complicated enough in themselves too, and because of their general usefulness they are not so much attached to certain engineering branches (e.g. computer simulation, engineering prognostication), and they cannot appear in the curricula of certain profession as independent subjects, or this is not necessary, either. Development gets quicker once in one then in another field of methodology (e.g. now in the field of analysis, now in the field of optimization, or statistical forecasts based on incomplete information, or in the field of weighted multi-criteria evaluation). However, the most important theoretical fundamentals and the most useful methods from these fields get, with some delay, into the fundamental and special subjects of engineering education.

The scientific field of systems engineering and engineer training have to be regarded as responsible for promoting the development and propagation of all procedures and methods which help the process of technical creation, and can contribute to the economical realization of technical products which are at the same time able to meet the demands and requirements of both the individuals and society, and to increase the security and quality of life.

As far as the state-of-the-art of a field of science can be determined, nowadays the following methods are generally mentioned as characteristic of systems engineering — of course the list can be extended: cybernetical and mathematical modelling, mathematical optimization, graph theory, network techniques, and other methods of operations research, analyses of system dynamics, optimal control, computer simulation, reliability theory, engineering and economic prognostication, statistical decision theory, correlation calculation, "cluster"-

analysis, and other methods of statistics, techniques of representation and rationalization methods helping technical creation, as well as complex evaluation of systems engineering and efficiency analysis.

As regards future, I should like to add to all this above that in our systems engineering analyses and problemsolving — especially in connection with problems of complex planning and control of production — we are getting more and more compelled to accept, besides the logic of rational decisions, that of heuristic decisions, besides the mathematical modelling of well-structured problems, the interpretative exploration of less well-defined problems, ways of rendering manageable badly-structured, unmanageable decision problems, besides optimum solutions, satisfactory ones as well. Thus the decomposed, multi-stage formulation of complex problems has come into prominence by way of communication, cooperation, and coordination between subproblems; the promotion of cooperation between various subtechniques; integration of prognostication and optimization model systems and of adaptive mechanisms as well as learning and search algorithmes; problems of elimination of special conflicts of objects; and interactive problemsolving. Obviously, to achieve all this, it is vital to develop creative skills and abilities, as well as those for interdisciplinary cooperation.

Prof. Géza JÁNDY H-1521 Budapest