SYSTEM SAFETY AS A STARTING POINT FOR EDUCATION AND TRAINING OF ENGINEERS

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Abstract

The interest in safety has been increasing largely in recent years. In the first place it is aimed to enhance well-being apart from the increase of prosperity. Secondly, life and well-being are more and more threatened by the growth of the surrounding systems on an extensive scale, such as dwelling, working and transportation systems.

The training of engineers does not sufficiently take into consideration these developments.
It is a fact that more and more individuals become victims of the effects of processes put into operation by man himself.
There are processes in use that not only menace the safety of individuals but may also have tremendous results when interferences occur. Moreover, there are processes with "by-products" the influence of which on human health will only show in the long run.
Engineers have always been fulfilling an important part in this matter, however, without taking into account in the research, development and design phases systematically all the output aspects of a system.
Nowadays when the development of aspects, such as unsafety, become more and more unacceptable, it can be seen that engineers are not equipped for controlling this unsafety.

In order to control the aspects of unsafety in dwelling, working and transportation systems, adequate methods of research and decision making are necessary.
These methods must be fit for dealing with comprehensive problems in which the study of interactions, such as relations between man and his environment, should be the guiding principle.
Yet, man is limited in his possibilities to perceive, decide and act. Moreover, human behaviour is greatly sitation-bound, which means that behaviour, given the tasks to be performed, and the internal conditions of the human being, are affected by external circumstances.

These circumstances, environmental conditions, are mainly created by engineers, who by doing so, have a great influence on human behaviour.

Weighting of well-being versus prosperity should also be possible. Unsafety is only one aspect of a certain system and should be weighted against other aspects such as the appropriate functioning of a system.

Based on all these, the training and work of engineers deserve further considerations as regards safety problems of our society. The development of a system approach, and an interdisciplinary approach focussed on todays problems, must also be taken into account.

Introduction

In the announcement of the SEFI Conference 1980 regarding "the education of the engineer in and for his society" it is mentioned: "The conference will discuss the differences and similarities in engineering education that are needed in various societies."
Based on my experiences in the field of traffic safety, as a managing director of a research institute and as a lecturer in "Transportation safety" at the Delft University of Technology, I should like to start with drawing a framework of thinking which is indispensable to me. On the basis of the approach to traffic safety problems I shall then submit a number of functional requirements to be met by the education and training of engineers in future.

Science and technology in the modern society

The fast changes that have taken place in western society during the last hundred years, have clear consequences for the ideas regarding the role of science and technology.

Science and technology have been exerting a strong influence on the world of today. One cannot deny that many technical developments contribute in a positive way to our prosperity and to our feeling of well-being.
In this connection I think for instance of automation in industry, as a result of which labour conditions had been improved, of the contribution of technology to medical science, as a result of which chances of recovery of ill and wounded people could be enhanced, and of modern means of communication and transportation what have widened our horizon, etc.
However, technical developments also bring many undesirable negative effects, such as the victims and the permanently disabled in transportation, working and dwelling systems, air pollution, noise, the menace of nuclear explosions, of contamination by radio-activity, the mishandling of animals in bio-industry, and many other.

The "technical world" is the result of the natural human urge for technical innovations. This process has begun from the first moment that human beings dwelled on earth. Entire stopping of this process is not only against human nature, but above all it is unrealistic.

The undesired negative "by-products" of technological developments are also caused by the products of the engineers, the technicians. The "technical products", however, are often used in a way not foreseen by the engineers.
In engineering it is unsufficiently taken into account that the human being is much more restricted in its possibilities to perceive, decide and act than the engineer often realises. Secondly, too often the fact is ignored that human behaviour is greatly situation-bound, in other words, in performing tasks, behaviour is "provoked" by external situations like the technical and social environment. This technical and (partly) this social environment are "created" by engineers. In this way they influence greatly human behaviour, mostly without realising sufficiently the extent of their influence. It is clear that elimination of technology cannot be the solution for the arisen problems. On the contrary, the modern engineer will have to play an important part in the struggle against the undesired by-products of his predecessors' work.
I depart from the idea that altering external situations, i.e. the environment, should be easier than changing people in such a way that they will adjust to the situations created.

The question now arises whether modern engineers will be capable of completely controlling the problems caused by their predecessors' work. In order to answer this question, investigation into the nature of these problems is necessary, regarded in the framework of the developments of society.
As a result of the rapid changes in society of the last decennia, the western world is entering the so-called "post-industrial period". In Scheme 1 a comparison is given of the characteristics of the "post-industrial period" with those of the "industrial" and the "pre-industrial period".

I shall emphasise more closely some of the differences between the "post-industrial period" and the "industrial period" in this framework:

1. Primary economic sectors (agriculture, mining, fishing etc.) and the secondary ones (goods-production, manufacturing etc.) are moving more and more towards the services sector (transportation, utilities, trade, real estate etc.) and the quinary sector (health, research, education, government, recreation etc.).

2. The aspects of well-being are getting more and more attention, while in the industrial period the increase of production was the main problem as a means of improving prosperity.
In the post-industrial period man discovers himself more and more as a victim of processes, designed and started mostly collectively by ourselves. The social values have changed. We found out that increasing the productivity is not the only aim of human life.

3. In the industrial period the emphasis was on improving fabricated nature and machine technology.
In the post-industrial period there are mainly discussions between persons and their ideas and an intellectual technology. Problematic situations and problems of this period are not absolute, but arise from the question: to which extent the undesired effects of developments can be accepted.

4. In the industrial period progress was achieved by creative, very talented inventors. These inventors mostly operated independently from organised research. E.g. Wright knew little of aerodynamics; Edison, Marconi and Graham Bell knew little of the scientific work of Maxwell, etc.
In the post-industrial period problems became more and more complicated. On the other hand the state of the art of scientific knowledge is such that "random inventions" can hardly be a source for technical progress and innovations. These have to be based on the codification of theoretical knowledge obtained from systematical scientific research.
In the post-industrial period the engineer must be capable of using codified theoretical knowledge from systematical research in such a way that he can manufacture products, which increase both prosperity

and well-being. He should prevent the undesired by-products to the best of his ability. He must apply knowledge to the restriction of unacceptable by-products of processes which already are in use. The engineers should always consider the following points:

a. What is the process to be controlled?
b. What for should it be controlled?
c. How should it be controlled?
d. Who controls what?

For the engineer plans, designs, builds and puts processes into operation, but man is the user and in the end society judges collectively whether developments are acceptable or not.
Through his education the engineer is mostly tended to start with the question: "how?". That is to say, he often starts with finding solutions for problems that are not sufficiently known from the point of view of society. The education of engineers in and for his society should start with the first two questions, in order to materialise his responsibility in modern society.

System approach

For controlling undesired by-products of systems, such as unsafety of the transportation system, adequate methods of research and decision making are necessary. These methods must be suitable for dealing with comprehensive and complicated problems.
Each scientific monodiscipline is deficient, whether regarding technical science or behavioural science. There is always an interaction between human behaviour and circumstances (technical environment).
If science is limited to the description and explanation of phenomena like unsafety, at least a multidisciplinary approach is needed. A team of technical scientists, behaviour scientists, lawyers, natural scientists etc. make researches into a phenomenon and bundle the important monodisciplinary knowledge (Scheme 2).
However, when the aim of the research is to control comprehensive and complicated phenomena, interdisciplinary approach is needed.

In this case we start from a different intersection of the real world. Different output aspects of systems or fields of society problems, are searched with the help of integrated (originally monodisciplinary) knowledge. Integration of this knowledge leads in fact to a new discipline, with his own conceptions and his own scientific research methods.

The control of systems and problematic situations with relation to aspects of systems in modern times, also asks for methods of decision-making in which weighting of different aspects is possible. Yet "production" and "by-products" are related to each other. Enhancing "production" has consequences for the "by-products", decreasing "by-products" has consequences for "production".

In the transportation system indicators as travel distance, travel time and travel comfort give an impression of the aim of the system. They are the production output variables of the system. If motorised traffic is increasing it has of course an influence on safety, air pollution etc. If we try to improve the safety by means of countermeasures like stimulating the use of seat belts, crash helmets, sufficient friction coëfficients for road surfaces, etc., it hardly has an effect on the production aspects of the transportation system, but speed limits or selective use of motorcars may have a positive effect on safety, but at the cost of the production aspects of the transportation system. Yet, society can decide (from a cost/benefit point of view) to imply these countermeasures, like it may decide to close a factory with heavy air polution, in case of air polution of that factory cannot be stopped by other means.

Interdisciplinary research and decision making on the basis of weighting output aspects, are the basic factors of the so called "system approach". System theory and methods are developed with more and more support and interest by scientists and decision makers and will function as a framework of thinking for controlling the problems of our time.

I mentioned the idea "system". Boulding defines a system as a whole of elements or objects influencing mutually, arranged according to a plan, in order to reach a certain aim.
The aim of system thinking is helping to bring the output of a system in the direction wanted by society. System thinking is not production oriented, but problem oriented. Therefore, the interaction between the elements is more important in system thinking than the characteristics of the elements itself.
Since every system is a sub-system of a larger one, choosing the right boundaries of the system model in fact settles the matter. If the boundaries are too large, the model is too complicated and research not very efficient. If the boundaries are too small, than important first order interactions may be neglected.
System thinking requires a structural analysis of problems before starting research and before thinking of control possibilities.
The questions mentioned before return here:

a. What is the process to be controlled?
b. What for should it be controlled?

What relations between the elements or objects within the system playing a part in the transforming process of input to output, are to be investigated, with relation to the aspect to be considered.
Also it should be assessed beforehand what is to be achieved by controlling a certain aspect with the help of certain countermeasures, and how far this may go at the cost of other, mainly "production" aspects.
According to my opinion there is no practice in problem analysis in the training of engineers.

Model of the accident process

The transportation system, in its present form and in its functioning, is, in fact, the work of monodisciplinarily operating scientists and decision makers. Town and transportation planners decide which roads should be built and where; traffic experts decide how the roads should be designed, road builders decide how these roads should be constructed and of which material.

Vehicle experts decide how vehicles should be designed and function, behaviour scientists and legal experts decide how the roads and vehicles should be used.
Strictly speaking everybody operates independently from the other, more or less without understanding the coherence of the system.

In general the processes that take place in a system as a whole, are too complicated to take all interactions into consideration. When the engineer has to concentrate on the interaction, for instance, between human behaviour and technical environment, he must break down the process into stages or subprocesses.
I would like to give you an example how the interactions between the elements (man, vehicle, road, environment), can be considered from one aspect of the transportation system, viz. the traffic safety, on the basis of a model of the traffic accident process.
In Scheme 3 the accident process is shown schematically: starting from a certain social activity, e.g. paying a visit somewhere, one will move with a certain vehicle. One gets involved in traffic situations, that influence the "own" traffic behaviour, and that "provoke" this behaviour to a far extent. For example, a road with wide lanes will provoke high driving speeds, even in a residential area.
Whether a critical coincidence of circumstances arises strongly depends on the "existence" of certain conditions and their predictability. But also one's "own" traffic behaviour plays a part in the approach of those circumstances. For instance, a critical coincidence arises when a road user approaches an intersection at high speed, with cross-traffic approaching at the same time.
If anticipating is possible, because the road user did the right observations and recognises this critical coincidence in time, a normal braking manoeuvre can be carried out. If normal braking is not possible in time, an emergency manoeuvre is needed and an incident or conflict arises. This not only demands ability of reaction and skill of the road user, but also a sufficient friction coëfficient between the road surface and the vehicle tyres, room for pulling out and adapted steering and sufficient braking characteristics of the vehicle.

If the emergency manoeuvre fails, an accident arises. Not only the road user himself, but also others can be the victims of the accident.
On the one hand the consequences (in terms of injury) depend on the forces that affect men during the collision, on the other hand the human tolerance is an important factor. The human tolerance is not the same for everybody. Young people have a far greater human tolerance than the aged. High death figures of aged people (in traffic and in the private sphere) can better be explained by the low human tolerance than by their restricted perceptive capacity or their reaction ability. Such restrictions are mostly compensated by "careful" behaviour.
At last here is the recovering phase. It is a pity that not all of the survivors will fully recover. Too less attention is paid to this aspect. The emphasis is on the high number of fatalities and injured. Within short time the Dutch research institute SWOV shall provide data concerning the number of permanently disabled persons caused by road accidents, added up over several years and per year.

The engineer plays an important part in all these stages of the accident process. He plays his part as a planner, as a designer, as a builder of system elements, and he regulates direct or indirect the use of these.
In every stage of the accident process the engineer must be able to recognise the interactions between his technical design and the relevant human characteristics like the behaviour of the road user in the first stages of the process and human tolerance in the last stages, in which also the environment plays an important role. As a specialist in planning, designing, building and regulating, every safety engineer should be capable of predicting and evaluating the effects of his "technical" activities on all stages of the accident process. He has to realise that a measure nearly always have influence in more than one stage of the process, sometimes in different directions, e.g. a positive effect in one stage and a negative effect in another.

Summarising, without being complete, I would like to draw the following conclusions:

1. The engineer of today is getting richer and richer with knowledge about the "technical" elements of systems, but is still poor in understanding the coherence of these elements in a considered system, especially concerning society problems such as (un)safety and well-being. In may experience, this understanding of the coherence can hardly be enhanced by just adding lectures in social science and behavioural science to the "technical" curricula, as is done on most technical universities.

2. Knowledge of the adverse effects of systems and technical measures should be considered already in the planning and designing phase. This is only possible by starting from a system approach, in which interactions between the elements of the system are analysed. In the engineering education or our days there is a lack of knowledge of the interactions between human behaviour and the "created" circumstances.

3. Engineers should be responsible for the "products" and countermeasures developed by them. Paternalism by political organs regarding developing or not developing of certain "products" or countermeasures, paralyses innovations. Political paternalism can only be avoided if the engineer is capable to assess the impact on the society, by carrying out problem analyses focussed upon society aspects. According to my experience there is a lack of practice in the training of engineers developping a problem oriented approach of thinking.

4. New interdisciplines must be added to existing scientific disciplines that are focussed on society aspects of the real world. One of those new interdisciplines should be the science of system safety.

Scheme 1. The Post-Industrial Society: A Comparative Schema (Source Bell, 1976)

MODES	PRE INDUSTRIAL	INDUSTRIAL	POST INDUSTRIAL
Mode of production	Extractive	Fabrication	Processing; Recycling
Economic sector	Primary Agriculture Mining Fishing Timber Oil and Gas	Secondary Goods-Producing Manufacturing Durables Non-durables Heavy Construction	Services Tertiary: Transportation, Utilities Quaternary: Trade, Finance, Insurance, Real Estate Quinary: Health, Education, Research, Government, Recreation
Transforming resource	Natural Power Wind, Water, Draft animals, Human muscle	Created Energy Electricity - oil, gas, coal Nuclear power	Information Computer and data-transmission systems
Strategic resource	Raw Materials	Financial Capital	Knowledge
Technology	Craft	Machine Technology	Intellectual Technology
Skill base	Artisan, Manual worker, Farmer	Engineer, Semi-skilled worker	Scientist, Technical and Professional occupations
Methodology	Common Sense, Trial and error, Experience	Empiricism, Experimentation	Abstract Theory: models, simulations, decision theory systems analysis
Time perspective	Orientation to the past	Ad hoc adaptiveness, experimentation	Future orientation: forecasting and planning
Design	Game Against Nature	Game Against Fabricated Nature	Game Between Persons
Axial principle	Traditionalism	Economic Growth	Codification of Theoretical Knowledge

Scheme 3.

Model of the accident proces	Relevant characteristisc traffic participant in accident proces
Social activities	
I	I Motivations of vehicle choice
Moving with a certain transportation mode	
II	II Assimilation of information
"Provoked" traffic behaviour	
III	III Assimilation of information and recognition
Critical coincidence of circumstances	
IV	IV Anticipation
Undesired incidents or conflicts	
V	V Reaction, recuperation
Collision (accident)	
VI	VI Human tolerance
Outcome (death, injury, material damage)	
VII	VII Tolerance - and recovery ability
Recovery, remaining invalidity	