ON CHAOS CONTROL IN HIERARCHICAL MULTI-AGENT SYSTEMS

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Abstract: The present paper is focused on the problems of chaos control in multi-agent hierarchical systems similar to the environment of the realization of automated factory projects. The basis for this research is a unique database of empirical studies of human faults and mistakes at the design and commissioning of factory automation systems. It is shown that for primary chaos control it is appropriate to use Design Structure Matrix (DSM) technology tools, enabling to describe synergistic relations between all teams’ members on the basis of the frequency and amount of information interchange. For further chaos control an effective system is proposed to track and hinder different human shortcomings spreading in the hierarchical teamwork system. As a basis for it an advanced simulation technique - discrete event modelling is used. The proposed methodology of suppressing the influence of human shortcomings allows us to increase the synergy in teamwork and to substantially reduce the losses of resources at starting-up new factories.

Key words: chaos control, factory automation, control systems design, teamwork management, synergy deployment.

1. INTRODUCTION

The losses of resources at the start-up of new automated factories caused by human shortcomings reach up to 5-10% of whole labour costs and tend to increase with the growing complexity of control systems. That is without any doubt too much, thus requiring the reasons for the misspent resources to be cleared up.

It is a reality that from the engineering side automation systems have become more and more complex. At the same time the amount of data and variables circulating in these systems have enormously increased. Therefore, the need for systems engineering is growing owing to a steady increase in systems complexity [1, 2, 3]. The described above technical background has paved the way for a substantial increase of the role of engineering competence and human shortcomings [4]. This situation has initiated a new wave of research into human shortcomings at the beginning of the present century [5].

The firm basis of any research in the field of the effectiveness of human cooperation is its reality database concerning empirical studies of human shortcomings. The existence of such a unique database gives confidence about “bad” engineering and authenticity of the results attained by theoretical research, developed on this basis. During the last 20 years, the authors’ research activities have been focussed on the empirical research into human shortcomings in the field of the quality of engineering design activities.

At first, a service database for non-safety-critical mechatronic office equipment was completed on the basis of which the concept of negative and positive synergy was developed [6]. Next a human shortcomings database was developed for factory automation design and commissioning, for the design of pneumatic and hydraulic control systems.
for industrial equipment and the design and production of serial light fittings. All these efforts were integrated into the fifth database of human shortcomings in quality management [7]. At the same time it has been the starting platform for the present research which was initiated with compiling a new advanced database of human shortcomings in factory automation systems design and commissioning. This database covers 26 automated factories on three continents, including pulp and paper mills, chemical and petrochemical plants and power stations [8].

The experience of the research group has shown that human shortcomings can be treated as a result of negative synergy in mutual or inner communication of team members and due to the lack of competence or inability in managing the teamwork in highly competitive environment [4]. In this context it is appropriate to define the concept of synergy which is used in the present paper. According to Oxford Dictionary the word synergy or synergism refers to the integration or cooperation of two or more drugs, agents, organizations, etc. to produce a new or enhanced effect compared to their separate effects. However, synergy has a qualitative and a quantitative side. Changing the input parameters of the system may result in dramatic changes in the system’s behaviour [9]. Qualitative changes in synergy have enabled using it in lattice dynamics, laser technology, superconductivity etc. Quantitative synergy effects have also been used successfully in business and engineering. Despite the wide existence of synergy effects in nature and artefacts, the real deployment of synergy in engineering is often hidden behind the terms of optimization, rationalization, effectiveness, etc.

For the better integration of all these matters the synergy-based approach is used in the present research, which aims to compensate mutual weaknesses and to boost the beneficial features at joining technologies and human activities. The synergy-based approach to the start-up difficulties of factory automation systems is comparatively new, providing a real opportunity to analyze the reasons of human-based start-up impediments and to plan the measures to avoid them [10].

2. CHAOTIC BEHAVIOUR IN HIERARCHICAL MULTI-AGENT DECISION MAKING SYSTEMS

In the calendar plan the process of automated factory design covers the drafting of the general description of the system, detailed task description for system configuration and a factory acceptance test, followed by commissioning. First of all, the owner names responsible persons in his team to keep watch on the progress of building a new production plant and to transfer his own requirements and necessary competence from the already existing production. Next, to run the project a consultant company is hired to integrate all efforts of project and commissioning groups. The task of the consultancy group is to forward the owner’s requirements to the process supplier(s). After that, it is necessary to collect the resound data from the process supplier(s), convert them into the required format, get approval from the owner and give this input information to the automation supplier. Then the automation supplier starts system configuration, including application software programming, human-machine interface and process interface configuration. After the configuration is complete and the automation system is tested in the workshop of the automation supplier (Factory Acceptance Test), it is delivered to the factory and integrated with the process supplier’s equipment. The activities continue with commissioning, where a lot of additional specialists are involved in the project team. A separate commissioning team is formed which includes members from project teams.
Also, the end users are part of commissioning, getting trained to run the plant at the same time.

The described above system is a hierarchy where the information of completed tasks is transferred from one team to another within the scheduled time. Such a multi-agent distributed artificial intelligence system is very sensitive to tainted information transfer \([11; 12]\). It is inevitable that an agent’s decision also depends on the decisions made by another agent upper in information flow. This obstacle makes the whole system extremely complicated and nonlinear. If agents use tainted or imperfect information, they tend to make poor decisions. In summary, it leads to the chaotic behaviour of downward agents and downgrading the performance of the whole system. In such a way human shortcomings may cause real chaos in automated factory design and commissioning.

For the present research a detailed database of human shortcomings in factory automation system design and commissioning for the years 2006-2013 was compiled. The newly introduced advanced classification of human shortcomings is shown in Fig. 1.

In this new database human shortcomings are divided into three main categories – faults, mistakes and strategic miscalculations. The faults class \(F_1\) includes all misunderstandings in communication between the client, consultant and the design teams or between design team members. \(F_2\) joins together all shortcomings connected with negligence. All transfers of unsuitable or late information and documentation in the design process are classified into the faults class \(F_3\).

Mistakes have a far more complicated nature. To this category belong wrong decisions \(M_1\), caused by lack of core competence. Mistakes \(M_2\) are conditional and are caused by the impossibility of predicting the production process characteristics at the moment of design and they may be resolved in the course of further projects activities. The third class \(M_3\) includes mistakes caused by system integration disability that leads to the situation where technologies cannot be integrated due to their different level of development. A new differentiated category of human shortcomings is strategic miscalculations \(S\). Contestable decisions \(S_1\) may be made due to the temptation to use cheaper or simple technical solutions that are not able to grant the necessary operating ability and quality. Contribution underrate \(S_2\) is a very spread phenomenon in a highly competitive society when under market pressure unreal obligations are accepted. A special category here is that of technical problems \(T\) which involve classical reliability problems.

In Fig. 2 the statistics of shortcomings for factory automation system design and commissioning is presented. For obvious reasons the factories involved are confidential.

As there are data included about 26 factories it is possible to presume the probability of any human shortcoming during the ongoing project. The impacts of shortcomings in the project for teams involved in automation design and commissioning are in average between 1500 and 3000 working hours. Additionally, there are losses of profit caused by the late start of production. The
real number and impact of shortcomings depends on the competence of the project team and also on the complexity of the task. As any of the shortcomings may lead to chaos its control is extremely important.

Fig. 2. Statistics of shortcomings for the design and commissioning the automated factories

Classical solutions for chaos control \([11]\) do not apply to the present specific hierarchical task and it is necessary to find a new strategic approach to solve the problem. In the present research a two-step approach is proposed. At first an exhaustive synergistic information transfer system should be created suppressing the development of chaos from the very beginning. And finally inhibitive chaos control for the spreading of human shortcomings must be developed.

The search for a powerful tool for describing human relations and grouping them on the basis of their cooperation tasks resulted in proving the Design Structure Matrix (DSM) technology to be the most suitable \([5]\). The additional value of DSM technology is the wide choice of mathematical tools to exploit the information concentrated in the DSM matrix. The mathematical treatment of DSM matrixes enables us to form the most capable teams, to schedule and evaluate their activities, to create an optimal communication and cooperation scheme where the competences and capabilities of the teams and their members can be entirely exploited \([13]\).

3. BASIC CONCEPTS FOR INHIBITIVE CHAOS CONTROL

The above described discussions have led to the understanding that the best way to cut losses of resources at automated factory design and commissioning caused by human shortcomings is to create an effective system to track and hinder the different human shortcomings spreading in the hierarchical teamwork system. In Fig. 3 the structure of the proposed system is presented.

Fig. 3. Impact of shortcomings on the whole project time

The formation zones of shortcomings are shown as integrated ones taking into account that origination of the human fault or mistake may happen at any moment on the time-scale. The same applies to the blocking zones of shortcomings. Behind the arrows of shortcomings impacts are the real working hours spent on the correction of the specific shortcoming impact. The overrun of the longest arrows on the time-
scale is conditional as it depends on how many human resources with necessary competence can be concentrated on eliminating the impact of shortcomings. As it is seen in Fig.3 the most dramatic losses can be caused by lack of competence (M1) and contribution underrate (S2). The project time depends on the complexity and novelty of the designed factory. The simplest projects last about 0.5 and the more complicated ones up to 4 years, having the average duration of 1...1.5 years.

The formation of human faults and mistakes is fully accidental and therefore project activities are more or less chaotic. However, the chaotic nature of designing and commissioning automated factory projects never results in a catastrophe where the project has to be stopped. During commissioning all the impacts of shortcomings will be removed and production will be launched. The profitability and competitiveness of a new factory is another question.

Planning the duration of a project has presumably a probabilistic nature leading to the field of soft computing. It is a very complicated area as at iterations the new or corrected information can appear at any moment of the process of rework. At the same time the amount of repetitive work is reducing according to the learning curve. On the basis of the probabilistic analysis of the wrong actions of decision-making agents special tracking maps can be completed enabling us to evaluate the probabilistic dangerousness of the different types of faults and mistakes. These maps are completed by integrating the synergy-based approach into information management with the use of an advanced simulation technique - discrete event modelling. This approach allows computing probability distribution of lead-time in the project network where iterations take place among sequential, parallel and overlapped tasks. So we reach the complete treatment of the evaluation of the time losses due to the faults and mistakes in information transfer taking into account necessary iterations, reworks and learning curves [14].

In Fig.4 the typical result of discrete event modelling is shown giving an idea of the probabilistic nature of any arrow in Fig. 3. Finalizing the results of the present research it is possible to aver that the full picture about the formation of human shortcomings, their impact and blocking activities has been attained. It is proved that the most powerful effect on the neutralization of human shortcomings is achieved by increasing synergistic information transfer procedures between all project teams and their members. As a result, a concept for the probabilistic evaluation of project duration is proposed, which is of great importance in project planning stage.

Fig. 4 Example of the probabilistic prediction of the time for shortcoming results removal

4. CONCLUSIONS

The research efforts in the area of automated factory design and commissioning have given sufficient evidence that most of the troubles with quality are caused by shortcomings in human activities. It is shown that a capable tool for suppressing human shortcomings is Design
Structure Matrix (DSM) technology enabling us to visualize the synergy relations in information interchange between both development projects working groups and between the group members. The DSM technology allows us to form the most capable teams and to schedule their activities and predict the time necessary to complete the project. The proposed methodology of tracking and hindering human shortcomings at automated factory design and commissioning presents an opportunity to increase synergy in teamwork and so to substantially reduce the losses of start-up new factories.

5. REFERENCES


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