

Shop Floor Control - A Integrative Framework

From static scheduling models towards an agile operations management

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ABSTRACT

Shop floor control is an object for research in various disciplines from engineering, management to the social sciences. No comprehensive framework or even overview on shop floor control research currently exists. As a result, many problems of the real world remain unsolved, because deterministic approaches - from research and practice - have significant drawbacks. Due to the fixation on mathematical solutions in traditional research, many potentials present in real world production are not considered, e.g., operator experience, motivation and qualifications, are not taken into account. The pragmatic approach of stable system design is based on a paradigm of social control through command and controllability and therefor tries to prevent any change and innovation as such.

1. SITUATION IN INDUSTRY

Manufacturing industries are facing a growing and rapid change. Major trends like globalization, customer orientation and increasing market dynamic lead to a shift in managerial principles: enterprises have to become more flexible, open, fast, effective, self-organized, decentralized, to sum it up: agile. On enterprise level this leads to a "shift from manufacturing to innovative, knowledge-based information and service application of products" [1].

Still manufacturing serves as a basic function for any agile enterprise. Manufacturing faces the same challenges as the enterprise as a whole. For the future, manufacturing can not only rely on technical excellence in machining, technologies and methods but has to achieve organizational excellence in knowledge, experience and motivation as well. The shop floor as provider of physical goods has to become an agile entity within the enterprise and within a network of enterprises forming a virtual organization.

The call for agility challenges the shop floor with several problems. With an increasing occurrence of changes and dominating customer demand, management of manufacturing processes and the coordination of the multifarious resources, i.e., machines, materials, information, knowledge and humans, becomes a core task for shop floor control. Besides not only an optimal management of the current situation is necessary but a continuous improvement of practices and performance.

This leads to the question of adequate design concepts for shop floor control. Assessing industry, global leaders, best practices

and hidden champions can be found. But in industrial reality at large, "the shop floor is not under control, it is out of control"[2]. Even though various solutions ranging from organizational strategies like group technology, team work and KAIZEN to technical solutions like MRP II, knowledge-based scheduling and genetic algorithm do exist, the problem of inadequate performance of shop floor control tends to remain omnipresent in most industrial enterprises until today.

The situation can be summarized by the following observations:

- (a) most current managerial concepts tend to address the overall enterprise and usually are very general and not focused on manufacturing industry or the shop floor respectively,
- (b) the shift towards the entrepreneurial function of management tends to leave manufacturing out of sight and often leads to the impression among practitioners that manufacturing is of no further importance,
- (c) while managerial literature deals with organizations, classic industrial engineering research still tends to neglect the organizational issues of shop floor control while simultaneously producing an immense number of highly theoretical and hypothetical solutions every year,
- (d) in industry shop floor control is overshadowed by the paradigm of 'command and control' leaving management to rely on power as means of ensuring effective control rather than any kind of conceptual approach. Therefor any conceptual approach as a means of altering the command structure is opposed. As a result, operators and workers are left with an increasing pressure replacing an empty prophecy of self-control.

2. STATE OF RESEARCH

Research on shop floor control has long concentrated on the scheduling problem and its solution. Solving an organizational problem underwent reduction to a mathematical model. Traditional approaches, such as those in Operations Research (OR), Industrial Engineering (IE), and some commercial software development try to achieve ideal scheduling systems by focusing on the scheduling process itself. The modeling techniques applied thus result in a simplification of the original problem. In contrast, most practical engineering approaches try to avoid any sophisticated scheduling as such and focus upon stable design of the manufacturing system and the requirements of systems control and controllability. The neglect of scheduling and control is omnipresent in most commercial

software packages which usually do feature no sophisticated scheduling solution. All these approaches still maintain the fiction of a deterministic world where one cause determines one result.

Shop floor control is an object for various disciplines from engineering, management to the social sciences. No comprehensive framework or even overview on shop floor control research currently exists. As a result, many problems of the real world remain unsolved, because deterministic approaches - from research and practice - have significant drawbacks. Due to the fixation on mathematical solutions in traditional research, many potentials present of real world production are not considered, e.g., operator experience, motivation and qualifications, are not taken into account. The pragmatic approach of stable system design is based on a paradigm of social control through command and controllability and therefore tries to prevent any change and innovation as such.

This situation produces a "theory-practice gap" [3] in shop floor control research which has been observed for several years. Up to today, most research still neglects the organizational impact of the problem and does not utilize the organizational potentials on the real shop floor. Even state-of-the-art textbooks do not focus on the organizational aspects of the scheduling problem and relegate the real world to footnotes.

3. TOWARDS AN INTEGRATIVE FRAMEWORK FOR SYSTEMS DESIGN

Still missing is an integrative framework for design and management of shop floor control which combines organizational and technological issues, acknowledges the dynamic nature of manufacturing processes and market behavior, and takes into account the sociopolitical impact for management and workers. What is necessary, is a framework which facilitates the change from deterministic scheduling models towards an agile operations management.

3.1 Generating knowledge: On the use of models

A major drawback of most quantitative approaches and particularly of most scheduling research utilizing OR methods can be seen in the role of models. In much research, the goal of building a model is to be able to derive an optimal solution within the model. This results in a predominance of the model itself, while the transformation back to reality is often omitted or not even possible. This is readily observed in the

great number of 'assumptions' that traditionally accompany many research papers. As PINEDO [5] states, „it is not clear how all this knowledge [gained through mathematical models] can be applied to scheduling problems in the real world“ (p. 253), since „real-world scheduling problems usually are very different from the mathematical models studied by researchers in academia.“ (p. 254). PINEDO then lists 10 problems that hinder the transformation of scheduling models into practice. Nevertheless, in the major part of his textbook, PINEDO describes static optimization methods only to finally admit that scheduling in reality has a „dynamic nature“ (p. 254) and is exposed to a „relatively high frequency of random events“ (p. 257).

What is lacking is the link to reality, an examination of the question as to what models are used for, and a methodology to transfer results back into the real world. As REISMAN & XU put it in an article on knowledge growth in the management sciences, „much of the institutional infrastructure, e.g., the graduate programs, the professional societies and especially the landmark journals have become inbred. They concentrate on research based on established paradigms, work which is essentially logic-deductive rather than grounded in reality.“

In an alternative approach, modeling can be seen as a means of generating knowledge about the system itself. That knowledge may then be utilized to determine possible and adequate changes to the system itself. Accordingly, it is not the model or the generation of an specific quantitative solution within the model which is the concern, but rather the process of modeling itself (Figure 1). The model „becomes a guide to the ways in which the system can be improved, [... rather than ...] a working tool for decision making in the system as it exists at the moment“ [6, p- 145]. It is within this perspective that OR methods gain relevance again as means of generating 'understanding'.

It is important to emphasize that the model-based approach will always result in a partial model of the 'real world' and thus only can provide a partial solution. It is this circumstance

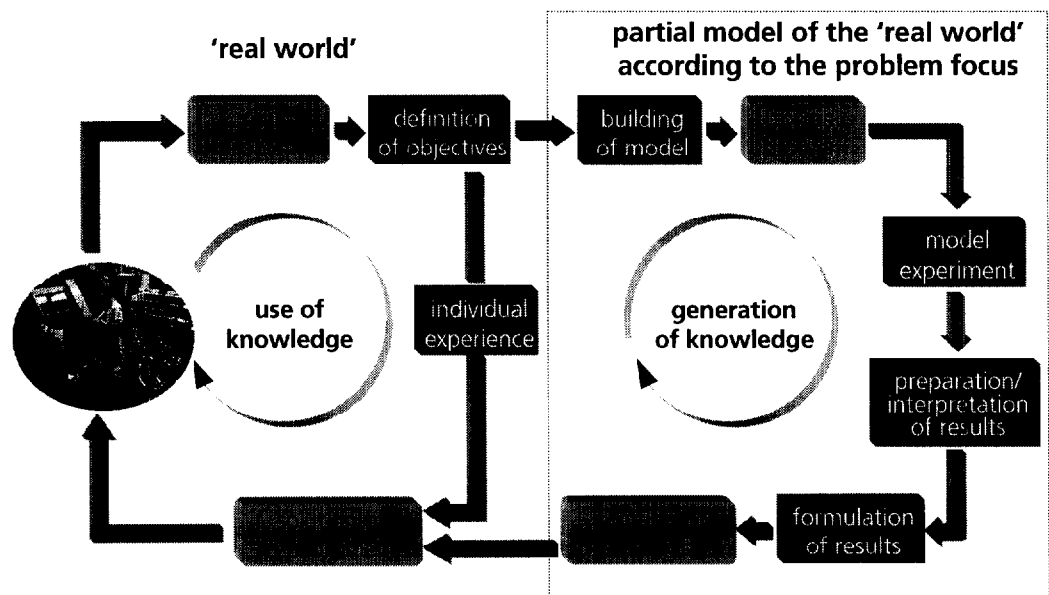


Fig. 1 Model based approach to problem solving [4].

which makes it impossible to create the 'perfect' framework for research. Multiple views and individual experiences, i.e., a thorough grounding in reality, are necessary in order to reach a holistic solution. Thus, the present volume presents different views to allow for more than one perspective.

3.2 Towards a systems perspective

Many predominant problems of the real world of production operations management stay unsolved, as approaches – both in research and practice – have significant drawbacks. The fixation on mathematical solutions omits several potentials present in real world production, e.g., operator experience, motivation and qualification. In a systems perspective the problem of control is not a problem of finding an optimal solution, but of establishing and developing a dynamic and flexible organization.

To achieve good solutions in the design of complex systems, a broad analysis of the underlying problem, combining various views, and a holistic approach is necessary. In this alternative approach, the design of shop floor scheduling and control can be seen as a task of systems design. Here, principle assumptions about the system and its underlying principles provide a normative foundation for the system designer. In the given context, the shop floor can be described as a system from two perspectives.

Cybernetic systems theory. Production operations as experienced at the level of the shop floor can be described as part of a larger cybernetic system which is highly complex [7]. Interactions, feedback and various couplings result in a non-linear system which is easily beyond the boundary of manageable complexity. Therefore systems behavior becomes unpredictable except for a very short-term period. As a result, the system appears to behave in a 'chaotic' manner in the perception of a single observer.

Cybernetical systems approaches allow to describe and understand the dynamics of behavior of the formal, logic system and its state variables as encountered in the real world.

Sociotechnical systems theory. Every production system consists of machines and some kind of human involvement. Accordingly, each production system can be seen as a sociotechnical system [8] in which humans and machines interact to produce an optimum result. The task of system design is to optimize both, the social and the technical subsystem. As experience in reality shows, the human controller is often the key to the system's effectiveness and provides the system's ability to function [9, 10]. Focusing on the design of shop floor control with the sociotechnical system as the framework therefore results automatically in a emphasis on the human role in production.

Sociotechnical systems approaches allow to describe and understand the courses of action and logic of organizational development of the informal system utilizing patterns of social and human behavior .

In the following, corresponding strategies of systems design are described. For effective systems design, the questions raised are:

- How may the controlled system be designed in such a way that its control be improved?

- How must the control system be designed?
- What principles are significant to control itself?

It must be noted that in production the control system and the system controlled can hardly be observed or designed separately. They are very closely linked in function, and in reality they become merged. This effect is reinforced by the sociotechnical character and the open nature of real production, which is subject to environmental influences.

4. TASK ORIENTATION AND STRUCTURAL DESIGN

The structure of a system represents a significant demand on the actors within a system. The structural design – of both the controlled system and systems control – is crucial to reorganization. If system structure is to be designed in a targeted way, the concept of structure must be examined.

Upon close observation, the structure of any organization reveals itself to be more or less dynamic [11]. Structure itself arises through activity within the system, and thus is based on the actions of the actors in the system. If activity ceases, the organization ceases to exist. As actions are not always the same and also can change form and type on their own through the course of time, we can define the structure of a system precisely only at an exact point in time. Such precise definitions quickly become irrelevant, however, because the structure of the system changes within a very short time. Change is effected through implicit self-structuring as well as through the explicit restructuring measures that are always part of a system and the environment of a system. In this sense, instead of 'structure', we may speak of the permanent 'structuring' of an organization. As WEICK [12, p. 18] notes, „Structures are both the means and the results of actions“. The actions are carried out by the actors within a system in fulfillment of their assigned tasks. In this way, the tasks assigned to actors within a system affect actions, which in turn serve to fulfill individual tasks. The structure of a system, therefore, is not defined exclusively by the formal structural and process organization of an enterprise, but rather results in its origin from the definition of work tasks, whose execution in operations generate the actual, dynamic structure of a system (Figure 2).

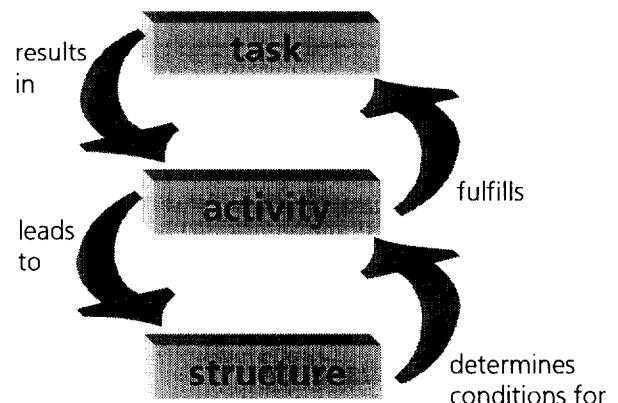


Fig. 2 The relation of task and structure.

In the design of a management and control system for production, the structure of the system and the individual work

tasks represent the most significant design parameters. Structural design is thus both a requirement of and a result of task design. There are no standardized solutions with regard to systems design. But it is possible to derive some rules of systems design. The goal must be to design a system which is flexible, adaptive and robust.

Because the work task is the basis for human action, while at the same time the human worker contributes considerably to the adaptivity of a system, a main emphasis must be placed on the task. It is necessary that the system be so designed as to allow use of and promotion of human abilities. System structure and, in particular, system complexity represent the most important demands and restrictions[13]. It must also be taken into account that in the framework of reorganization, task design is more amenable to definition and implementation than the comprehensive structure of a system. In turn, task design always has an effect on structure. This structuring effect may take hold very slowly and not always in a predictable form. Task design achieves a certain, yet temporary, system state. This changes with time and can lead to positive or negative effects on the total system.

Work tasks should be designed according to work- and human-oriented criteria [14]. This allows human potentials to be utilized and, at the same time, a positive work environment is created for people. Humane systems design and economically sound systems design are not mutually incompatible.

4.1. Design principles

In the following, human-oriented and structurally-oriented principles of systems design will be outlined and shown in relation to task design. System structure provides the frame for the entire system, in that it establishes the

- autonomy and
- interconnection (linking)

of the cells. The prerequisite for true autonomy of a cell is, in addition to the autonomy to act (sufficient degrees of freedom for decision-making), autarchy. Autarchy is to have the necessary resources at one's disposal. Cells become interconnected via material flow, the exchange of resources and, independently thereof, the exchange of information. The linking of cells determines the effect relations among them. Here information exchange may take place in the form of horizontal or vertical communication, that is, directly between two operational cells or via a hierarchically superordinate cell.

The degree of the autonomy to act and of the complexity to be regulated are, from the perspective of the cell, significant features which determine the degree of effectiveness of control within a cell. They are manifested in the transparency of the work task, in possibilities of intervention and in authorization to intervene, in process understanding and the qualifications of workers.

ULICH [15, p. 156] makes the following demands upon the structure of a sociotechnical system to ensure task orientation, which are to be met at the level of the organizational unit:

Relatively independent organizational unit. Is the organizational unit – due to the completeness and independent nature of the task assigned – in a position to itself counterbalance and regulate any interferences and variations at

the location of their appearance, so that these do not reverberate in an uncontrolled fashion to other organizational units?

Task relatedness within an organizational unit. Are the various part-tasks in a work system related in content? Are work-related communication and cooperation required by task fulfillment? Is there a shared understanding of the task?

Unity of product and organization. To what extent may the work results of an organizational unit be attributed to itself both quantitatively and qualitatively? Can errors or deficits in quality be traced clearly back to the unit? The unity of product and organization allows the unit to identify with its own product.

Through relative independence, task relatedness and the unity of product and organization, it is possible to create teams which may act with clear reference to their surround in the total system.

4.2. The role of autonomy

Teams controlling themselves are only then successful, when the total task does not exceed a degree of complexity which accords with the level of qualifications. „If system interferences become so large or so complex that their mastery within the system overtaxes resources, then it becomes a necessity to shield the group from the interferences“ [16, p. 35]. The control of these interferences then falls to a superordinate coordinating instance or a superior. A change in the autonomy of a decentralized area and a change in the degree of freedom for action show contrary effects. On the one hand, a minimum level of complexity of the task is required if improvement is to be made. On the other hand, the human worker is limited in his proactive control of complex processes. Based on these considerations, ULICH [17] formulated the hypothesis as early as 1974 that there is an inverse, U-shaped relationship between the degree of effectiveness of work – expressed in the relation between mental and physical expenditure and the performance achieved – and the degree of complexity of a task (Figure 3).

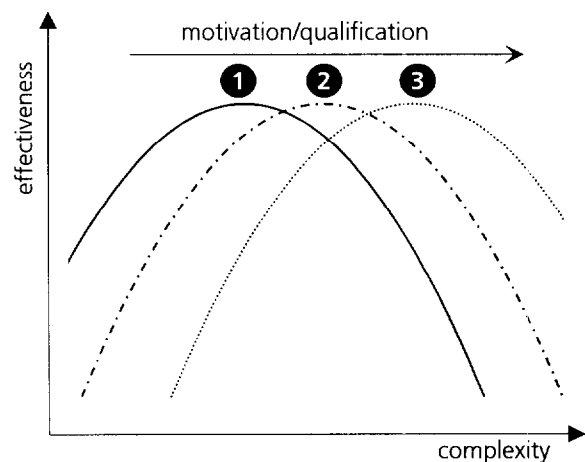


Fig. 3 Probable relationship between degree of complexity of work activity and degree of effectiveness of human work[17, p. 193].

To design a system of lasting effectiveness, design must strive towards continuous adaptation of the total system to enduring changes in the surround system. More than primary, temporally limited flexibility is thus required: the entire system must be designed to be adaptive. Here again, the human, as coworker in a cell, is the primary initiator and bearer of possible change. Entrepreneurial thinking leads the cell, through self-organization, towards the goal of creating its own optimal conditions of work. This results in the active modification of structure and tasks from the perspective of operations. Adaptation of the system as a whole is thus achieved via self-organization of the cells. Here the important catalysts are the opportunity to take over further activities with simple environmental conditions, and the need to adapt one's own actions when demands are complex. The extent of change made independently and adaptively is arbitrary and begins with changes in one's own work procedures, with possible spread all the way to change in the goals of the whole system.

System complexity thus represents the essential measuring variable in designing system structure, in that it determines the degree of effectiveness of human work as well as the autonomy strivings of individual cells. Of course, the complexity of a system may not be viewed as something that stays the same in a lasting way. Instead, complexity is already subject to the structuring process mentioned. The goal of systems design must therefore be the creation of an initial design of the system which allows for and promotes continuous adaptation. There are several conceivable principles here. For one, participation of those involved would foster an understanding of a reorganization project as a process of change from its very start and would allow reorganization efforts to continue in that same vein. Deliberate cutbacks in resources can cause a demand for adaptation and, thus, force self-organization and change. WIENDAHL & AHRENS [18,p. 4] speak here of „interventionist control“. Or in another strategy, entrepreneurial action can be promoted by means of an appropriate systems of incentives, by setting up certain market principles among the cells. Here it becomes clear that the shielding from interferences and variations may not go so far that the cells give up their strivings toward autonomy. Shielding must take place only in individual cases. This makes the degree of shielding, in relation to the extent of external demands, a dynamic variable, which can be controlled, so to speak, at the level of management and via the control network.

4.3 Integration in distributed systems

While autonomy has to be achieved through a strategy of decoupling the cells, integration depends on a certain coupling of the cells and coordination of the cells' activities. As means to achieve integration the following principles can be helpful:

Common objectives. Pursuing a goal is the basic principle enabling activity. A specific goal always depends on the personal interpretation and motivation of an individual. The activity of a single cell has to be integrated into the overall system of objectives of the global production system. This can only be achieved through motivation and incentives. Therefore it is necessary to allow local and even personal objectives in addition the objectives proposed by the higher management.

Integrated information systems. Computer-based information offer various means to integrate distributed and decentralized organizations. Thereby it has to be considered,

that computer-based systems never will be able to realize a total integration within a sociotechnical system there the human individual still is a major resource. Rather than globally imposing activities and procedures they should support local activity by distributing information throughout the system.

Network organization and personal communication.

An integrated organization has to picture the dynamic structure of the system and the system's environment. This can be achieved through a network organization of interlinking teams where each team is part of the higher level activities through a representative. This representative forms an 'linking pin' between the different cells and the different levels of management [19].

In respect of integration it has to be considered that integration is the ability of an organization to flexibly act towards a common goal rather than a specific state of an organization of being integrated. Therefore the personal ability to interact and communicate flexibly and efficiently is a major objective for system design.

4.3 Self-design and lasting adaptability

In order to guarantee the lasting efficiency of the organization of shop floor control as described, there is a need for the creation of lasting opportunities for organizational development, for learning and for the acquisition of knowledge. To design task that allow learning and knowledge acquisition, the following are required:

- Ability to learn: Qualifications and motivation
- Opportunity to gain experience: Interferences and errors
- Opportunity to apply knowledge: Independent actions

Lasting opportunities to reflect as a group and as an individual and to further develop one's own behavior and performance have to be created. It will be necessary to give work teams the opportunity to examine, question and design their tasks and conditions for execution, as well as their personal and collective goals. This process would include ultimately the question of the meaning of one's work. This leads to a kind of expanded feedback loop (Figure 4), in that not only the direct behavior of a cell, in the form of quality control, is examined, but also the work task, goals and meaning, or necessity, of the cell as an organizational unit within the company.

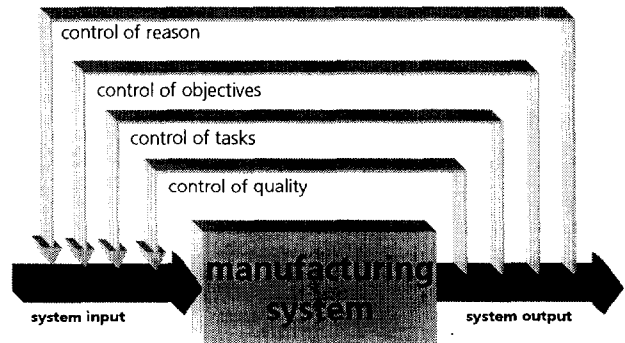


Fig. 4 Expanded control system [20].

As individual cells become able to reflect upon the organization from their local perspective, they will contribute considerably to a continuous increase in the flexibility and

adaptability of the entire production system, without being prodded to do so from above. Within this layout self-design ensures the system's ability to adapt to a changing situation without changing the overall hierarchical framework.

5. SYSTEMS DESIGN FOR FLEXIBILITY, ADAPTIVITY AND STABILITY

Several principles for systems have been described based on some basic assumptions on how systems and organizations function and what can further human characteristics. The more open a system is the more it has to be able to act ad hoc and independently. To enable optimal behavior and results of shop floor control it is necessary that strategic management in an enterprise rather allows more autonomy at shop floor level than introduces a highly automated and sophisticated computer system for scheduling. Thus achieving flexibility, adaptivity and stability for shop floor control always will result in a change of power and hierarchy in production management. It is this very basic assessment which shows that the process of systems design for shop floor control never can be purely neutral since it always involves humans and their individual will.

LITERATURE

- [1] Goldman, S.L., Nagel, R.N., Preiss, K. (1995): *Agile Competitors and Virtual Organizations*. Van Nostrand Reinhold, New York.
- [2] Melnik, S.A., Carter, P.L., Dilts, D.M., Lyth, D.M. (1985): *Shop Floor Control*. Dow Jones-Irwin, Homewood.
- [3] King, J.R. (1976): The theory-practice gap in job-shop scheduling. *The Production Engineer*, 3, 137-143.
- [4] Wiendahl, H.P. (1996): Grundlagen der Fabrikplanung. In: Eversheim, W., Schuh, G. (Eds.): *Produktion und Management*. Vol. 2. Springer, Berlin. p. 9-1 – 9-31.
- [5] Pinendo, M. (1995): *Scheduling: Theory, Algorithms and Systems*. Prentice Hall, Englewood Cliffs.
- [6] Burbidge, J.L. (1978): *The principles of production control*. 4th Ed. MacDonald & Evans, Plymouth.
- [7] Dobberstein, M. (1998): Control on the verge of chaos – analysis of dynamic production structures. In: Scherer, E. (ed.): *Shop floor control – A systems perspective*. Springer, Berlin.
- [8] Susman, G. (1976): *Autonomy at work: a sociotechnical analysis of participative management*. Praeger, New York.
- [9] McKay, K.N., Safayeni, F.R., Buzacott, J.A. (1988): Job-Shop scheduling theory: What is relevant? *Interfaces*, 18:4, p. 84-90.
- [10] Sanderson, P.M. (1989): The human planning and scheduling role in advanced manufacturing systems: an emerging human factors domain. *Human Factors*, 31:6, p. 635-666.
- [11] Emery, J.C. (1969): *Organizational planning and control systems*. Theory and technology. Arkville Press, London.
- [12] Emery, J.C. (1969): *Organizational planning and control systems*. Theory and technology. Arkville Press, London.
- [13] Scherer, E., Dobberstein, M. (1996): Komplexität in der Produktion beherrschen? *IO Management Zeitschrift*, 65:3, p. 60-64.
- [14] Scherer, E., Zölch, M. (1998): IT at the shop floor – Criteria-based methodologies for human-machine Task Allocation. In: Scherer, E. (ed.): *Shop floor control – A systems perspective*. Springer, Berlin. p. 291-310.
- [15] Ulich, E. (1994): *Arbeitspsychologie*. 3rd ed. vdf/Poeschel, Zürich/Stuttgart.
- [16] Alioth, A. (1980): *Entwicklung und Einführung alternativer Arbeitsformen*. Verlag Hans Huber, Bern.
- [17] Ulich, E. (1974): Neue Formen der Arbeitsstrukturierung. *FB/IE*, 23, p. 187-196.
- [18] Wiendahl, H.P., Ahrens, V. (1995): Planning and control in self-organized production systems. *WGP Annals Production Engineering*, II:2.
- [19] Likert, R. (1961): *New patterns of management*. McGraw-Hill, New York.
- [20] Henning, K., Marks, S. (1993): *Kommunikations- und Organisationsentwicklung*. Verlag der Augustinus Buchhandlung, Aachen.