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Document Version
Publisher's PDF, also known as Version of record

Publication date:
2000

Citation for published version (APA):
Slomp, J., & Ruël, G. C. (2000). *A socio-technical approach for the design of a production control system: towards controllable production units*. s.n.

A Socio-Technical Approach for the Design of a Production Control System

- Towards Controllable Production Units -

Jannes Slomp and Gwenny C. Ruël

SOM theme A: Primary Processes

Abstract

In the design of a production control system much attention is usually paid to technical aspects, whereas the elaboration upon social aspects remain underexposed. Sociotechnical Systems Theory (SST) emphasizes the importance of finding a joint optimization between the technical and the social systems of an organization. This paper investigates to what extent STS-principles can be applied in the design of a production control system. Part of the paper is devoted to the integration of STS-principles in a bottom-up design methodology for a production control system. A case study demonstrates the usefulness of such an integration in the design and allocation of production control tasks and responsibilities among the various departments /people of the firm.

1. Introduction

Many companies are facing tighter market demands regarding the price, quality, variety and delivery time of their products. They will have to arrange the production organization so that these demands can be met. This often implies a restructuring of the means of production or a change in the structure and system of production. Flexible, automated means of production are purchased and thus arranged to allow an efficient and effective product flow. Many firms have also decided to apply cellular manufacturing, or team production, to be competitive in the market place. Usually production control, too, needs to be adapted. There will be growing pressure on balancing sales and production and using means of production and workforce as efficiently and effectively as possible. The contribution of this paper is that it explores the application of concepts from socio-technical systems design to the production control domain and demonstrates the applicability with a case study. Brown et al. (1988, pp.266-267) mention the need to apply socio-technical principles in the design of a production control system. In their opinion, *the relative failure of many 'production management systems'* (here: production control systems) *can be explained, at least partially, in terms of the lack of a true socio-technical approach to the design and installation of these systems (pp.266).* They criticize the overemphasis on the technical aspects of production control systems and argue that disappointments arise because of failure to give regard to the social aspect system. Hyer et al. (1999) present a case study illustrating 'a socio-technical systems approach to cell design'. Part of the cell design, as they present it, concerns the determination of production planning and activity control procedure. An important socio-technical aspect of this part of the cell design is, in their case study, the fact that cell operators were assumed responsible for material ordering, job tracking, and scheduling. This ensured a certain level of autonomy of each manufacturing cell. The decentralization of control tasks required user-friendly information systems and training of the operators to use the new simplified systems. A material council (with representatives from each cell and production planning) was made responsible for the development of information flow procedures across the cells. Van Eijnatten and Van der Zwaan (1998) present the current Dutch socio-technical design approach to integral organizational renewal. Part of this approach is the design of a control structure, including production control. According to Van Eijnatten and Van der Zwaan, an important concept in the socio-technical design of a production control system is *the control loop in which all different control aspects merge*. Closed loops within organizational units support the autonomy of groups. This can be seen as a plea to give workers the production planning and control responsibilities needed to deal with the variances in their work, such as the absenteeism of colleagues and machine breakdowns. Although Brown et al. (1988), Hyer et al. (1999), and Van

Eijnatten and Van der Zwaan (1988) stress the importance of a socio-technical systems approach for the design of a production control system, they do not explore the application of the various concepts of socio-technical systems design to the production control area. This paper is meant to fill that gap.

Section 2 will shortly describe the basic philosophy of socio-technical design. Section 3 gives a brief explanation of the basic elements of a production control system. Next, section 4 makes a link between socio-technical principles and the (re-)design of a production control system. Section 5 presents a re-design approach for a production control system, which offers a framework for the integration of the relevant socio-technical principles. Section 6 concerns a brief description of the firm for which the production control system was re-designed. The case described in section 6 serves as an illustration of the various elements, or steps, in the (re-)design approach. Sections 7 to 10 explain the various steps in more detail and apply them to the case. These sections also explain how the socio-technical principles are integrated in the re-design approach. Finally, section 11 is a conclusion section.

2. What is a sociotechnical design?

An important approach which supports the integration of human factors in industrial settings is the so-called socio-technical systems (STS) approach. The term ’socio-technical systems’ originates from Trist and Bamforth (1951), at the Tavistock Institute. On the basis of an empirical case, they describe the importance of finding a ‘joint optimization’ between the technical and social systems of an organization, even if this leads to suboptimal conditions for the systems individually (Emery and Trist, 1972; Herbst, 1974; Cherns, 1976). The technical system concerns the technical-economical aspects and the social system refers to all of the social aspects of the functioning of an organization. Both aspect systems have an impact on the performance of a firm and must be optimized simultaneously in an organizational renewal process. An improvement in one system, without considering the effect on the other system, may deteriorate the overall performance of the organization.

The basic premise of the socio-technical systems theory is the principle of 'organizational choice' (Trist et al. 1963; Hage, 1977), which means that technology does not necessarily determine the organizational arrangement of human tasks (known as the technological imperative), but that it still leaves design-space. In the socio-technical viewpoint, the organizational arrangements determine the fit between the technical and the social systems. In conformity with these thoughts, socio-technical design approaches are basically focused on the (re-)design of the organizational structure.

Another essential element in STS is the notion of organizations as open systems. Open system theory states that entities and situations outside the organization can affect what happens within it, and the organization, in turn, can influence what happens in and around it (e.g. Child, 1979). Based upon the open system approach, one may define socio-technical re-design as the process of rearranging tasks and responsibilities in order to create a new 'input - transformation - output' situation. In a closed system approach, organizational redesign is only focused on the transformation process itself.

The basic starting point of the socio-technical approach is the conviction that the existence of a controllable situation is of immanent importance for the survival of an organization. The socio-technical insight on the matter of controllability is built upon 'the law of requisite variety' of Ashby (1969), which states that variety can only be controlled by variety. The translation of this law into STS terms implicates that in order to realize a controllable situation the number of control measures inside an organizational unit should be at least as large as the number of variations (from inside or outside) which affect that particular organizational unit. Or as Weick (1979) puts it: “only variety can regulate variety”. Based upon this law, the socio-technical approach distinguishes two design strategies. In the first strategy, socio-technical (re-)design attempts to reduce the number of variations. This can be done, for instance, by subdividing the organizational unit into smaller units (in terms of machines, equipment, workers, etc.), each responsible for a particular family of products. Each family-unit is confronted with only a certain segment of the environment, and consequently with less variety. In the second strategy, socio-technical (re-)design attempts to add (or decentralize) control tasks to an organizational unit which is facing variety. This increases the number of measures that can be taken in the organizational unit. Some socio-technical literature (especially the Dutch Socio-technical Approach, see e.g. Kuipers and Van Amelsvoort, 1990 or Van Eijnatten and Van der Zwaan, 1998) suggests a certain logical sequence of the two design strategies. First the production structure should be re-designed in which teams, or cells, are created that are relatively independent from each other with respect to their primary tasks. This corresponds to the first design strategy of reducing the internal and environmental variety. Next, the control structure has to be re-designed in such a way that the teams, or cells, are able to deal with the variety. As will be seen in this paper, the logical sequence of the design strategies is debatable.

The socio-technical systems approach is important for the design of a production control system because such a system involves a technical and a social aspect system. The technical system can be regarded as the set of abstract models of planning, scheduling and control as presented in Production and Operations Management literature. Also software tools and information systems can be seen as part of the technical system. The models, tools and information systems do usually not incorporate the human aspect of production control, such as the division of decision tasks and the social and psychological characteristics of the people who will be made responsible for planning and control tasks. The socio-technical systems approach advocates a strong focus on the organizational choices in the design of a production control system. These choices concern the design and division of production control tasks among employees. As will be made clear later on in this paper, such a focus on organizational choices may have an impact on the design of the technical system. The socio-technical approach assumes that its particular focus will create the best fit between the technical and social systems of a production control system. Section 4 will further specify the socio-technical guidelines which may be useful in the design of a production control system.

3. What is a production control system?

This section gives a brief overview of the elements and aspects of a production control system. First, a more general introduction is given in which major production control concepts are explained. A global hierarchical structure of a production control concept is presented which encompasses the major elements in each production control concept. Second, a socio-technical view on production control is given by presenting the major aspects of a production control system which have to be considered in a (re-)design.

A production control system is a major part of the control structure of a firm and is responsible for the planning, scheduling and control of the activities. It usually has a hierarchical character. Several arguments can be given to justify a hierarchical approach to production control problems:

- *Reduction of complexity.* Production control problems can generally be characterized by the presence of multiple, sometimes contradictory, objectives and a number of complicating and to a certain extent conflicting constraints. A hierarchical approach offers the possibility of splitting up complex interrelated production control problems into several small solvable parts.
- *Separation of short-, medium-, and long-term aspects.* Production control problems on a long-term level are generally more strategic in nature than medium-term and short-term problems and therefore demand different solution methods.
- *Improving stability and controllability.* Production control problems may arise at regular and/or irregular intervals. Without a hierarchical decision structure all the (interrelated) production control problems are affected by any disturbance. A

hierarchical approach offers the possibility of solving problems on one level without the need to replan on higher levels. This improves the stability of the production control decisions and severely reduces the amount of information required.

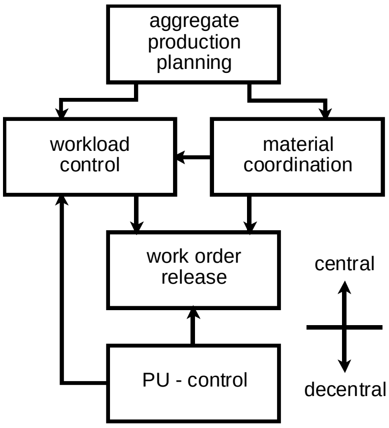

Figure 1 Global hierarchical structure of a production control concept (Bertrand et al. 1990)

Figure 1 presents a global hierarchical structure of a production control decision system. Bertrand et al. (1990) describe the elements of the structure as follows. "*The aggregate production planning level forms the connection with the higher levels of control in the production organization. At this level integration takes place of the various control aspects of the organization (sales, logistics, quality, finance, personnel, etc.) In a situation with standard end-items the outputs of the aggregate production planning process are the aggregate delivery plan, the capacity use plan, the capacity adjustment plan, and the aggregate inventory plan. These four plans are the driving force for the short term capacity control and material control. In material coordination, priorities are determined for the release of work orders. These priorities are based upon detailed demand information (sales) and on the work order throughput times of the various stages in production. The detailed demand information used in material coordination is directed by the aggregate delivery plan (part of aggregate production planning). Actual work order releases are determined on one hand by the priorities given by material coordination and on the other hand by the release possibilities from the aggregate release pattern (output of the workload control function). The aggregate release pattern is determined by the capacity use plan of aggregate production planning and by controlling the workload of the production units (or work floor). The release possibilities can be further* *restricted by other (finer) operational constraints of the production units and by material availability. The process that determines the releases is called work order release. The process that determines the aggregate release pattern is called workload control. Inputs for work load control and work order release are the capacity use plan of the aggregate production plan and the work order priorities from material coordination". (Bertrand et al. 1990, pp.56).* Production unit control (PU-control) concerns the production control decisions (who, where and when decisions) on the work floor. The functional elements presented in Figure 1 have to be specified in the design of a production control system.

Vollmann et al. (1991) give an overview of the main production planning and control concepts used in industry. All these concepts can be related to the hierarchical framework of Figure 1. The Material Requirements Planning (MRP) concept is a job-oriented concept that translates the overall plans for production into the detailed individual steps necessary to accomplish the plans. The elements of Figure 1 can be seen as separate functions in the MRP concept. The Just-in-Time (JIT) concept is oriented towards a smooth flow of materials through the firm in such a way that customer demands can be met without controlling the progress on the shop floor. In terms of Figure 1, JIT streamlines the execution on the shop floor and, by doing so, simplifies the PU-control (e.g. KANBAN-system). Workload control and material coordination are integrated into the aggregate production plans. Basic principle of the production control concept of Optimized Production Technology (OPT) is that bottleneck operations are of critical scheduling concern. OPT calculates different batch sizes throughout the plant, depending on whether a work center is a bottleneck. In terms of Figure 1, OPT attempts to combine the material coordination and workload control function by means of a bottleneck approach. Hierarchical Production Planning (HPP) is a planning concept which starts from the information of an aggregate capacity analysis. Disaggregation of this information provides the required information on lower levels of the production control hierarchy. In terms of Figure 1, HPP performs the workload control and material coordination function at various levels of a production control hierarchy, applying different levels of aggregation. Bitran et al. (1988), who developed the concept of HPP, stress the need to match product aggregations in HPP to decision-making levels in the organization. Disaggregation should follow organizational lines. This statement comes close to a more socio-technical definition of a production control system as is presented in the remainder of this paper. Larsen and Alting (1993) indicate that the various production planning and control philosophies are usable in different, sometimes overlapping, industries. MRP is meant for complex multi-level batch manufacturing and assembly, JIT, as production control mechanism, can be used in high volume production and assembly of simple products. OPT is developed for multi-level batch and process flow manufacturing and assembly of high volume and high complexity products. HPP is basically developed for a low volume, high variety process industry. Larsen and Alting (1993) also present the concept of Distributed Production Planning (DPP). This concept proceeds from the idea that information technology enables the move from a centralized concept, as MRP and OPT, to a decentralized system in which each production unit has to control its own materials flow. Within the DPP approach, concepts like MRP, OPT and JIT may support the production control in the various production units. As will be seen later in this paper, the socio-technical design approach to production planning, scheduling and control can be seen as a particular elaboration of the DPP approach.

From a socio-technical viewpoint, a production control system can be regarded as consisting of three aspect systems: (1) a decision hierarchy, (2) an organization hierarchy and (3) an information system and decision support tools, see Figure 2. The decision hierarchy of a production control system concerns the arrangement of decision tasks. Each level of the decision hierarchy reduces the complexity but also limits the decision space of lower levels. Figure 1 can be seen as a global structure of the production control decision hierarchy. The decision tasks, described in the decision hierarchy, have to be fulfilled by one or more levels of the organization hierarchy of a firm. Each level of the organization hierarchy reduces the scope of responsibility for subsequent lower levels. The decision hierarchy and organization hierarchy determine the framework in which the information system and the decision support tools should fit appropriately. A well-working information system is essential for a successful implementation of a decision and organization hierarchy. To enable the decision tasks at the various organizational levels, decision support tools may be needed. The three aspects of a production control system are strongly interrelated. The need for computerized decision support tools, for instance, depends on the chosen decision hierarchy.

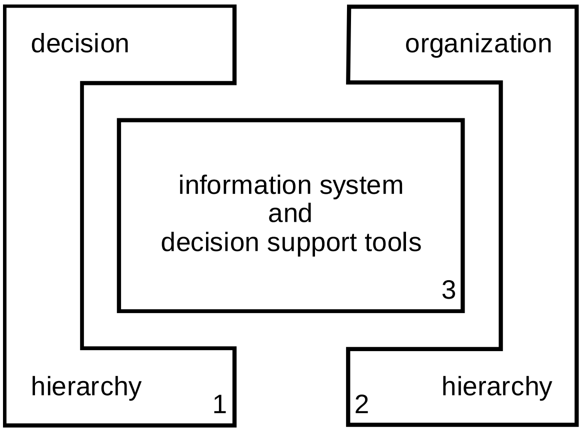

Figure 2 Aspects of a Production Control System

Furthermore, the qualification and experience of the people responsible for certain decision tasks may determine the desired abilities of the decision support tools. The decision hierarchy, the information system and decision support tools can be seen as the technical system in the socio-technical system approach. The design of the organization hierarchy encompasses, in socio-technical philosophy, the aspects which determine the fit between the technical and the social systems.

4. Sociotechnical design principles and guidelines

A key term which may cover the original meaning of the socio-technical idea is ’self-organization’. The open system approach and the focus on gaining a controllable situation point in the direction of a careful development of self-organization. Self-organization has to be realized through the design of a production structure as well as the design of a control structure. Self-organization has to be seen as a means to realize the objectives of an organization and its workers. Each situation requires its own degree of self-organization. The more complex tasks are, and the more variety to deal with, the higher the required level of self-organization. Self-organization, furthermore, refers to the result of the design process as well as to the design process itself (see e.g. Cherns, 1987).

Table 1: Socio-technical design principles

Compatibility	The way in which design is done should be compatible with the design’s objective.
Minimal critical specification	No more should be specified than is absolutely essential. What is essential should be specified.
Variance control	Variances should not be exported across unit, departmental, or other organizational boundaries.
Boundary location	Boundaries should not be drawn so as to impede the sharing of information, knowledge, and learning.
Information flow	Information for action should be directed first to those whose task it is to act.
Power and authority	Those who need equipment, materials, or other resources to carry out their responsibilities should have access to them and authority to command them.
The multi-functional	If the environmental demands vary, it then becomes more

principle	adaptive and less wasteful for each element to possess more than one function.
Support congruence	Systems of social support (systems of selection, training, conflict resolution, work measurement, etc.) should be designed so as to reinforce the behaviors which the organization structure is designed to elicit.
Transitional organization	The design team and its process should be seen as a vehicle of transition.
Incompletion	Design is a reiterative process. The closure of options opens new ones. At the end we are back at the beginning.

A well-known list of socio-technical design principles, which supports the idea of self-organization, is given by Cherns (1976 and 1987). Table 1 gives a brief summary of the principles. Several authors have used the list of Cherns as a starting point for analysis. Huber and Brown (1991) use Cherns' list to recover human resource issues in cellular manufacturing. Hyer et al. (1999) apply the principles of Cherns in the design of manufacturing cells.

The socio-technical principles can be applied in the design process of a production control system, as will be shown in the remaining part of this paper. The sequence of the principles in the list, however, is somewhat random. Some of the principles refer to the (re-)design process, some principles concern the characteristics of an ideal design, and, finally, some principles refer to the environment of the ultimate design. The next three subsections reorder the principles. Subsection 4.1 transforms the principles into procedural guidelines, i.e., guidelines which are helpful in the process of gaining a planning, scheduling and control system. Subsection 4.2 presents guidelines by which the ultimate design of a production control system can be evaluated. Subsection 4.3 contains the guidelines for obtaining a good fit between the design of a production control system and its environment. Subsection 4.4 summarizes all of the guidelines.

4.1 Procedural Guidelines

As mentioned before, the application of socio-technical principles supports the idea of self-organization. An important question is *how* to gain an organization, or a production control system, which is based upon the idea of self-organization. Three design principles mentioned by Cherns (1987) may be helpful in answering this question: compatibility, minimal critical specification, and transitional organization.

Compatibility. Cherns argues that the process of design must be compatible with its objectives. Quote: "If the objective of design is a system capable of self-modification, of adapting to change, and of making the most use of the creative capacities of the individual, then a constructively participative organization is needed. A necessary condition for this to occur is that people are given the opportunity to participate in the design of the jobs they are to perform." Application of this principle on the subject of this paper means that the planning and control system should be developed and implemented in participation with the people who will have a task in the system. Generally spoken, participation will improve the quality and the acceptability of a new planning, scheduling and control system The last statement, however, is of relative value. Research in the area of Management Information Systems has shown that user participation in the development of a system is less important for highly structured and well-defined systems. Participation in the development is critical when information required to design the system can only be obtained from the users, or if the system causes significant changes to the jobs of employees (Ives and Olson, 1984). Barki and Huff (1989) have studied the necessity of participation in the implementation of Decision Support Systems. Their survey showed a strong correlation between user participation and the success of the support system (i.e., user satisfaction and system use). However, it may be clear that participation has to be regulated in order to avoid a hotchpotch of opinions.

Minimal Critical Specification. As Cherns states, this principle has two aspects, a negative and a positive one. The negative aspect simply states that no more should be specified than is absolutely essential; the positive aspect requires that we identify what is essential. The two aspects can be applied in the process of gaining a production control system. The negative aspect demands that design problems should not be formulated too tight. A problem of a limited availability of cutting tools, which may cause serious scheduling problems, for instance, can be solved by purchasing extra cutting tools, or by implementing an intelligent planning or scheduling procedure. If these two possibilities are present, then the designer of a planning and scheduling system (or the design group) should not exclude one. The positive aspect of the principle of minimal critical specification requires that the designer identifies the essential, or critical, design problems or constraints. If, for instance, the firm is not willing to invest in new machines in order to simplify the production control, then this fact has to be accepted as an important design constraint. These examples also illustrate some links between the design of a production system and the design of a production control system.

Transitional Organization. Cherns (1987) states that "the design team and its process need to be seen as a vehicle of transition". It is not unusual in design practice to distinguish a design and an implementation problem. The designer (or design team) is responsible for the first problem, the client (or firm) has to deal with the second one. Cherns stresses the need to close the gap between design and implementation. As a consequence of the principle of ‘transitional organization’, one should give the designer (or design team, including the participating employees) the responsibility for the design as well as for the implementation of the new production control system. The division between design and implementation is also criticized by Ackoff (1979). A solution for a practical problem which is not implemented, is not a solution. Design and implementation are two connected activities. Implementation will, almost inevitably, ask for redesign, and redesign asks for implementation.

According to the socio-technical systems theory, the design principles mentioned above have to be used in the process of designing and implementing a production control system. Not using the principles may be the reason for a failure.

4.2 Design Guidelines

A production control system can be described by its decision hierarchy, organization hierarchy, the information system and the decision support tools. Socio-technical design principles may be helpful in taking those design decisions which optimize the self-organization on all levels of the production control hierarchy. The following principles seem to be applicable: minimal critical specification, variance control, boundary location, the principle concerning the information flow, the multifunctional principle, and the incompletion principle.

Minimal Critical Specification. As mentioned before, this principle has a negative and a positive aspect. Both aspects can be applied in the design of a production control system. The negative aspect states that on each hierarchical level no more should be specified than is absolutely essential. In this way flexibility is left for subsequent levels of the hierarchy. The positive aspect states that each hierarchical level should give the necessary directives which enables an optimal functioning of a manufacturing system. In a bad design of the decision making hierarchy it would be possible to frustrate the decision making tasks at certain levels by inaccurate solutions derived at previous levels. The principle of minimal critical specification is, to a certain extent, a plea for decentralization of production control tasks. Several authors support this plea. Child (1984) stresses the need to increase the human abilities and to decentralize the decision making in order to react appropriately on disturbances of the production process and changes in the market. Decentralization, furthermore, offers the possibility to activate hidden human abilities. This is likely to improve the quality of labor (Kuipers et al., 1990). Another aspect of the principle of minimal critical specification concerns the question what has to be established for each level of the production control structure. Cherns (1987) distinguishes objectives and methods, and discusses the overall need of establishing methods: "While it may be necessary to be quite precise about what has to be done, it is rarely necessary to be precise about how it is done". This statement may depress the sometimes irresistible challenge of designing methods which optimize a certain objective.

Variance Control. Cherns states that variances should not be exported across unit, departmental, or other organizational boundaries. This means that each organizational level in a production control system should be able to cope with the variances that may arise at that level. In other words, decision making tasks (levels) should reflect the variances that may arise at the organizational level.

Boundary Location. This principle says that boundaries should not be drawn so as to impede the sharing of information, knowledge, and learning. The principle contributes to the considerations with respect to the assignment of decision tasks and responsibilities to the organizational levels. Principally, all levels should contribute to the overall objectives of the production control system. Because of the complexity of the planning and scheduling functions, however, each of the levels of the decision and organization hierarchy may have its own objectives. It is required that these objectives are tuned to one another. A system of co-ordination (= sharing of information, knowledge, and learning) is needed to avoid sub-optimizations.

Information Flow. "This principle states that information systems should be designed to provide information in the first place to the point where action on the basis of it will be needed" (Cherns, 1976). This principle has to be seen as a design and evaluation criterion for the information system. The required design of the information system depends on the division of tasks and responsibilities. In a situation of centralized responsibility the information system should be able to collect and transfer detailed information, such as order status, actual level of capacity and loading, actual scheduling and the availability of material. A detailed data recording system as well as a control system for short-term instructions will probably have to be installed in case of centralized responsibilities. In case of more distributed responsibilities, where production control tasks are performed more locally within extensive margin, it may be possible to take advantage of the personal know-how of the workers at each organizational level. The appropriate support for these workers may be specific decision support tools, which enables them to keep control over their local sub-area.

Power and authority. This principle states that "those who need equipment, materials, or other resources to carry out their responsibilities should have access to them and authority to command them" (Cherns, 1987). This means that in a production control system, people cannot be made responsible for taking good decisions if they do not have the means and/or authority to take and execute those decisions. This principle may seem a matter of course and of common sense. However, in many practical cases, people are given responsibility for a high delivery performance without having sufficient decision support tools and information to plan and control the process.

The multi-functional principle. This principle states that multi-functionality of employees will make the organization more adaptive and efficient with respect to a varying environmental demand (Cherns, 1987). The principle of multi-functionality is also of importance for the design of a production control system. Decision support tools, which can only be used by one employee, for instance the foreman of a work group, are not usable if the employee is absent. In order to serve the multifunctional principle, it can be argued to construct the decision making hierarchy in such a way that the complexity of each decision task is as small as possible. It will then be easy to instruct more than one person taking the decisions. Complex decision tasks can be simplified by implementing intelligent decision support tools.

Incompletion. Cherns (1987) criticizes the myth of stability, which so easily accompanies the designer (or design team). Cherns says: "Although the myth of stability is essential to enable us to cope with the demands of change, we all know that the present period of transition is not between past and a future stable state but really between one period of transition to another. The stability myth is reassuring but dangerous if it leaves us unprepared to review and revise". Following this warning, the changeability of the production control system should be helpful in dealing with a changing situation. The changeability, for instance, can be expressed by a modular structure or by the simplicity of the system.

The design principles mentioned above, has to be seen as guidelines and evaluation criteria for the designer (design group) of a production control system.

4.3 Environmental Guidelines

A production control system has to perform in an organizational environment. The organizational environment needs to support the well-functioning of the production control system. One socio-technical principle refers to the organizational environment: the principle of ‘support congruence’.

Support Congruence. "Systems of social support should be designed so as to reinforce the behaviors which the organization structure is designed to elicit" (Cherns, 1976). The introduction of a new production control system can urge the need for a training program, or even the hiring of new employees. Also the payment system may be changed because of the new production control system. One may think of the impact of more control responsibility for the salary of workers. Important, furthermore, is the congruence of work measurement systems with the responsibilities enclosed in the production control system. It would, for instance, be incorrect to measure only the efficiency of operators, if they have also the responsibility of processing the orders in time. The lack of support congruence can be the reason for the failure of a production control system.

4.3 Summary of the Guidelines

Previous sections have presented several guidelines for the socio-technical re-design of a production control system. Table 2 summarizes the guidelines. These guidelines are independent from the particular production control concept (i.e., MRP, JIT, OPT, HPP). The guidelines do not give suggestions about how and when they can be integrated in a systematic (re-)design approach. The remainder of this paper contains an illustration of how to integrate the guidelines into a systematic (re-)design approach. Section 5 will briefly present the steps of the proposed (re-)design approach. Section 6 describes a real-life case situation for which a production control system has been re-designed. Sections 7 to 10 illustrate the integration of socio-technical principles into the steps of the design approach.

Table 2: Guidelines for the re-design of a production control system

Procedural Guideline 1 (Compatibility)	Users of the production control system should participate in the design.
Procedural Guideline 2 (Minimal Critical Specification)	Only essential constraints should be specified.
Procedural Guideline 3 (Transitional Organization)	The designer is also responsible for the implementation of the production control system.
Design Guideline 1 (Minimal Critical Specificaton)	Only essential decisions should be taken at each level of the production control hierarchy. These decisions concern merely objectives instead of procedures for lower levels.
Design Guideline 2 (Variance Control)	Decision making tasks (levels) should reflect the variances that may arise at the organizational level.
Design Guideline 3 (Boundary Location)	Each level in the decision hierarchy may have its own objectives. Coordination between levels (e.g. by sharing of information, knowledge, and learning) may be required to avoid sub-optimizations.
Design Guideline 4 (Information Flow)	Information systems should be designed to provide information in the first place to the point where action on the basis of it will be needed.
Design Guideline 5 (Power and Authority)	People can only be made responsible for decision tasks if they have the means (decision support tools, information) to deal with the decision problems.

Design Guideline 6 (The Multifunctional Principle)	More than one employee should be able to deal with each decision task in the production control hierarchy. This can be easily realized if the decision complexity at each decision level is low. Decision support tools may be helpful in making decision problems less complex.
Design Guideline 7 (Incompletion)	The production control system must be easy to re-design. This can be realized by means of modularity and/or a basic simplicity of the decision problems.
Environmental Guideline 1 (Support Congruence)	Training programs, salary systems, work measurement systems, etc. need to be congruent with the design of the production control system.

5. Approach for the design of a Production control system

The production control system of a company can be compared to the nervous system of the human body: all positions within a company are connected to the coordinating role of production control system. A proper design of the system is therefore crucial to an effective and efficient operations management. This section presents a design-oriented approach to production control. The basics of the approach are derived from the work of Bertrand et al. (1990). Figure 3 gives a schematic overview of the approach.

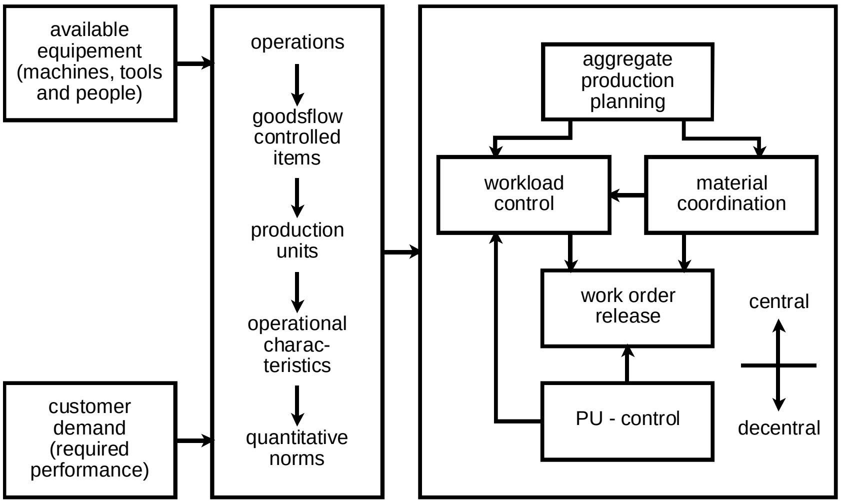

Figure 3 Approach to the design of a production control system

First, operations are defined based on the company's means of production. These operations can be regarded as its smallest, independently controllable units. Next, a distinction is made between items (output of operations) requiring central control and items to be controlled in a decentralized way. Centrally controlled goods are called 'Goods Flow Controlled Items' (GFC items). To a certain extent, these GFC items determine the limits of the production units (PUs) that are controlled centrally but comprise operations that can/should be controlled in a decentralized way. The PUs are defined in such a way that they are relatively independent of each other in the short term and responsible for the production of a specific set of half-products/end products. A PU can be regarded as a set of operations. Next, the operational characteristics of the PUs need to be carefully defined, first in qualitative terms. When releasing work for the PUs, central production control will have to take these characteristics into account.

On the basis of the market situation (what is important for the customer) and the operational characteristics, the firm has to decide for a logistic structure (what to make on stock, and what to make on order) and has to define the order lead times of the PUs to be reserved. Simultaneously, norms for the operational characteristics need to be set. The order lead times to be reserved can be seen as important quantitative information to be used in the central production control functions. Subsequently questions regarding aggregate production planning, workload control, material co-ordination, work order release and PU-control have to be answered. Section 3 gives a brief explanation of these production control functions. As mentioned in section 3, the socio-technical approach can be seen as an elaboration of the Distributed Production Planning concept. This means that the relation between each PU and the central production control may be based on its own specific concept (which may have the character of MRP, JIT, OPT, HPP, or such).

Sections 6 to 10 will explain the approach in more detail, illustrating how socio-technical principles may guide the designer of a production control system. This is done on the basis of a real-life case study in which the production control system has been re-designed using the elements of Figure 3. At the time of the re-design, the socio-technical principles were not explicitly integrated into the approach. Therefore, the case study only serves as a tool to show the possible integration of socio-technical principles; it does not proof the usefulness of the principles. Section 6 presents the particular case. Section 7 gives an explanation of how the firm has defined its production units (PUs). Each PU has its own specific operational characteristics that production control (the central control) should take into account. The definition and content of these characteristics will be addressed in section 8. Section 9 concerns the order lead times of the PUs and the choice of a logistic structure. Next, in subsection 10, the content of the elements of a production control system (PU-control, work order release, material co-ordination, workload control and aggregate production planning) are discussed.

6. Case study

The firm presented in this case study concerns a small company of about 60 direct employees, in the north of The Netherlands. Since 1915, the firm produces a large variety of perforated sheet metal which it supplies as half-products or end-products to nearly all branches of industry. Perforating is an industrial process in which numerous holes of random shape and size and in various patterns are made fast and efficiently in plate material. The company has its own tool manufacture where perforating equipment is manufactured and serviced. Other activities besides perforating include rolling, cutting, setting and rounding corners. Figure 4 gives a schematic representation of the primary production process.

The firm manufactures standard perforated and special purpose perforated plates. The perforations of the standard perforated plates are listed in a catalogue for customers to choose from. They are made with existing equipment. The standard perforated plates (with current perforation and merely rolled) are supplied to wholesalers. However, in view of the huge variety of simple standard perforated plates, no stock is kept. Furthermore, the company supplies more complex standard perforated plates to various customers. These plates have standard hole patterns and undergo one or a few additional modeling processes besides perforating and rolling. For instance, check plates, filters, balcony rails and ceiling boards. The special purpose perforated plates refer to custom-made perforating tools. The catalogue does not include this sort of perforations so production requires special equipment. They make up around 6% of the total number of orders per year. Naturally many customers place repeat orders for their special purpose perforated plates.

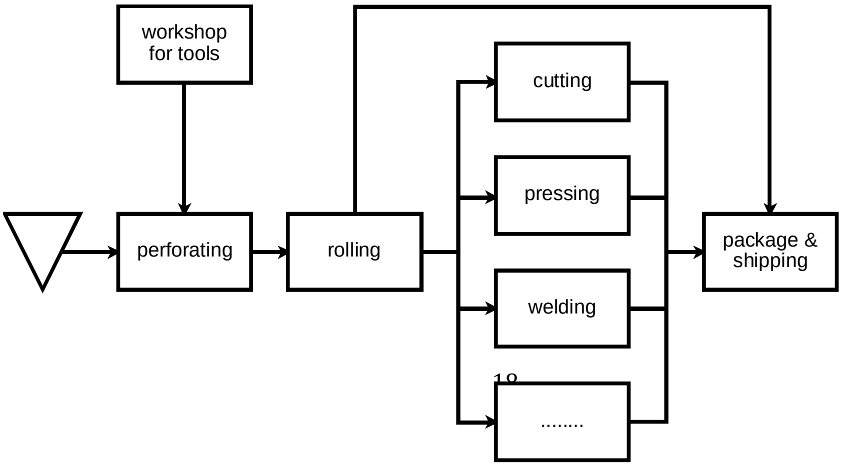

Figure 4 The primary production process

The firm is facing tightening market demands. There is a call for extra processes other than perforating as well as a greater variety of perforations. Moreover, there is a growing need for short and reliable delivery times together with competitive price levels of perforated plates. To meet the demands the firm has introduced tighter production control. The approach used to re-design the current production control system is schematically presented in Figure 3. The next section will illustrate the approach in more detail, showing the relation with socio-technical guidelines.

7. Operations, GFC-items, and Production Units

As can be derived from Figure 3, a proper definition of production units is at the basis of good production control. To this end operations and GFC items first have to be carefully identified, and next the limits of the production units in which several operations are combined.

7.1 Operations

In the production process, an operation is the smallest unit that can be controlled independently. In practice an operation comprises a group of processes that have little autonomy with respect to the moment of release. The operation processes are carried out together in a certain, logical sequence. Within the firm, the perforating process is an example of such an operation. It consists of clamping a roll of plate material, adjusting tools, making a hole pattern and cutting to size. Also rolling can be included in the perforating process. Almost all perforated plates need to be rolled. This is done immediately after the perforating process. Defining operations can be best done participatively with the employees of the firm *(socio-technical procedural guideline 'compatibility').* They know best the activities to be performed on the shop floor and they are able to describe the operations in some detail. The following operations were distinguished within the firm:

(a) perforating and rolling;
(b) (circular) cutting;
(c) eccentric pressing;
(d) rounding corners;
(e) squaring;

(f) stretching (straightening; smoothing);
(g) welding;
(h) manufacturing tools;
(i) packing and shipping.

Expediting, i.e. shipping the end-products to customers, is done by an external transport company working on call. This means that the expediting operation is quite an easy, administrative task (the firm merely has to phone the haulage company) so it is not included here any further.

7.2 GFC Items

The next step is to identify those stages in the goods flow requiring central control. At this point the so-called GFC items are defined; these involve the materials, half-products, and end-products that are generated during the goods flow and preferably need feedback coupling to and from a central production control department. Centralized production control decisions are needed to deal with deviations from scheduled times and quantities. These deviations may have an impact on the whole goods flow. As few GFC items as possible should be defined *(socio-technical design guideline: minimal critical specification)*. Three elements are of major importance in selecting GFC items: fluctuations/uncertainty in demand and supply of items, the product structure and capacity bottlenecks (Bertrand, 1990).

Fluctuations/uncertainty can be found in the demand as well as in production. In practice, uncertainty in demand occurs with the end-products (customer demand) and with the products/parts that have to be transformed into end-products on customer order. The latter are kept in the so-called CODP (customer order de-coupling point) and are produced on stock and/or forecast. In view of an unstable demand, the end-products and the CODP products/parts are preferably GFC items. In the specific situation of our case, the end-products and the raw material, which is purchased on stock, are GFC items. Information on (the availability of) these items in a centralized production control function is important for realizing and maintaining an efficient and effective production system. Production uncertainty may also be the reason for defining GFC items. The uncertainty may be related to the risk of machine breakdown, variations in the required production time and capacity, the varying availability of production capacity, etc. As for the particular firm presented in this section, uncertainty is found especially at the perforating machines and some of the finishing operations. Therefore, products which have undergone a perforating (incl. rolling) operation and products which have undergone a finishing operation are considered GFC items. The central production control will need information on them for a smooth running of follow-up activities (such as the extra start-up of a series).

Product structure is the second element that plays a role in defining GFC items. It is particularly important for complex assembly situations that require the timely availability of all parts for (sub-) assemblies. These parts make up GFC items. Central control is advisable specifically for parts that are used for various (half-) products (i.e., parts with a large ‘commonality’). The firm in our case study manufactures a single product. Still, two GFC items can be distinguished. At the start of production two elements must be available at the same time: plates/rolls (i.e., the ‘raw materials’) and perforating tools. Consequently, they can be regarded as GFC items (this had already been concluded for the plates/rolls).

The third element used for defining GFC items relates to the importance of the production means and whether or not it constitutes a capacity bottleneck. The occupation of such a process has a considerable impact on the productivity of the entire company. The incoming and outgoing products/parts of a bottleneck are GFC items; central control of the bottleneck is required in view of its impact on the entire goods flow. At the particular firm the perforating machines are considered the bottlenecks of the company.

Table 3 represents the GFC items distinguished in the particular case:

Table 3: GFC items

raw material
tools for perforating
perforated and rolled plates
plates after finishing operation
final products

They are the starting point for the definition of production units (PUs). A change in product structure or the purchase of new, and better, equipment may reduce the number of GFC items. The designer of a production control system should take care of the *socio-technical procedural guideline of minimal critical specification.* New finishing equipment, for instance, may lead to avoiding the fifth GFC item (i.e. plates after finishing operation).

7.3 Production Units

As mentioned before, a PU is relatively independent and responsible for the production of a specific set of half-products/end-products. In principle the GFC items represent the incoming and outgoing flows of a PU and must be planned by a central control department. By doing this, the PUs are buffered from variances which they cannot control *(socio-technical design guidelines Variance Control).* In the case presented here, four PUs are identified: (1) the tool manufacture, (2) perforating and rolling, (3) finishing processes, and (4) packing. Each PU is responsible for one or more operations. In case the finishing-PU comprises many machines and people, the final processing department, if necessary, can be split up into smaller PUs (using group technology). This, however, is not necessary for the firm involved.

8. Operational Characteristics of the Production Units

To facilitate the release of orders from a centralized production control function to the independent production units, the characteristics of the PUs should be considered. In general four operational characteristics can be distinguished (Bertrand et al. 1990): (i) batch quantity constraints; (ii) sequence constraints; (iii) workload constraints; and (iv) capacity constraints.

Batch quantity constraints. The set up times during perforation are considerable so it is advisable to produce large batches in the perforating and rolling PU. The production-order size is determined by customer-order size. This means that the firm's sales department and customers must agree on which batch size is minimally acceptable. In case of very large customer orders, the production control department may decide to split some orders. The batch quantity constraints of other PUs are less severe than with perforating. Given the dependence of the perforating/rolling PU it is not necessary to include batch quantity constraints in the set of operational characteristics of these production units.

Sequence constraints. As for the perforating process, careful consideration of the order sequence may result in a significant reduction of changeover times. Time is saved if only the roll of plate material has to be replaced and tools can remain in place (or vice versa). This could be arranged at central control level. However, there is more local knowledge on the shop floor, for instance on the standing time of moulds, so decisions on sequence are preferably taken at workshop level *(socio-technical design guideline minimal critical specification)*. Here, 'preferable order sequences' can be more effectively balanced against 'realizing internal delivery times'. This means that central production control should allow the perforating/rolling PU some play concerning the moment of starting an order. This can be realized by offering the production unit a significant amount of Work in Process to choose from. The other PUs have no or hardly any sequence constraints.

Workload constraints. The accepted orders determine the utilization, or occupation, to be realized (workers and machines). From a financial point of view, a maximum utilization of each source of capacity would naturally be best. However, as Figure 5 demonstrates, this would have negative consequences for the lead times to be realized. With a high degree of utilization long waiting times will occur. The choice of the maximal workload to be assigned to people and machines should therefore allow for reasonable lead times. The capacity of the workers in the perforating/rolling PU can be easily adjusted to the number of perforating machines in use and does not have to be included as one of the operational characteristics. In the final processing PU human capacity is the determining factor for the production to be maximally realized (with an acceptable lead time). Thus, the number of people present in the final processing PU together with their ‘occupation' can be viewed as operational characteristics. The utilization of the machines in the final processing PU is generally low so they form no operational characteristics to be reckoned with by central production control. In the tool manufacture the production to be realized depends on the number of people. Work pressure here is determined by the number of new perforating devices (tools) to be made and the number of tools to be serviced. For the packing department, the number of workers, again, determines how much work can be done. The work volume varies considerably.

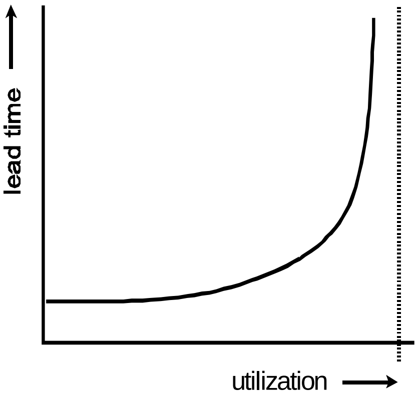

Figure 5 Relation between utilization and lead time

Capacity constraints. The capacity constraints of the perforating/rolling PU are due to the number of machine hours available. Extension is only possible through overtime work. If the need for extra capacity continues, the switch to a three- or four-shift system may be considered. Capacity extension of the final processing PU can be realized by hiring temporary workers. After all, the available capacity here is determined by the number of man-hours available and training periods are generally brief. The other PUs, too, have capacity constraints (in this case the number of workers). Capacity extension of the tool manufacture, however, will only be necessary in case of a substantial increase in orders. The capacity need in the tool manufacture can be balanced by repair jobs. If necessary, packing can be done with workers from the final processing PU or with temporary workers.

The operational characteristics of the various PUs are summarized in Table 4. These characteristics have to be dealt with in a central production control function. By doing this, autonomy of the PUs can be facilitated by central control (*socio-technical design guideline variance control and boundary location*). Furthermore, the characteristics play a major role in balancing sales and production. The sales department will have to take account of the operational characteristics when making arrangements with customers. The specific interpretation of these characteristics, on the other hand, such as the necessary capacity and workforce will depend on market characteristics. Tuning sales and production is based on the definition of the norm-lead times of orders by the various PUs. This will be discussed in the next section.

Table 4: Operational Characteristics of the Production Units

Production Unit	Operational Characteristics
tool manufacturing	• Number of employees • Workload per employee (number of new and repair tasks)
perforating and rolling	• Minimal batch sizes of orders • Minimal amount of Work In Process (to enable the PU to optimize the sequence of production orders) • Number of perforating machines and their capacity • The capability for overtime work • The capability to go to another shift system
finishing processes	• Number of employees and their capacity (in hours per day) • The capability to make use of temporary employees
packing	• Number of employees and their capacity (in no. of orders per day) • The capability to extent the capacity with workers from the final processing PU or with temporary workers.

9. Norm lead times for orders

The definition of the norm lead times of orders within the various PUs is of crucial importance when tuning sales and production. These norm lead times depend on market characteristics (what is important for customers) and the logistical structure (what is made on order, what is made on stock) of the firm. The norm lead times should take into account the operational characteristics of each PU. The norm lead times of orders in PUs can generally be calculated using the following formula:

$$LTR_{ij} = p_{ij}+w_jn_{ij}$$

LTR_{ij} equals the lead time to be reserved for order i in PU j, p_{ij} is the total processing time (including set up times) required for order i in PU j, n_{ij} is the number of processing steps (or operations) of order i in PU j, w_j is the waiting time per processing step in PU j. In view of the sequence and batch quantity constraints it is important for the perforating/rolling PU to have the option of combining orders and lining them up. Consequently, ample waiting time, w_j, must be reserved. The final processing PU can do with a shorter waiting time, w_j. For the tool manufacture (particularly the manufacturing of new tools/perforating equipment) and for the packing department fixed lead times can be chosen independent of specific orders. It is important that the total lead times are acceptable to the market. If total lead times are generally not acceptable for customers, the firm may choose to perform several PU-operations on forecast. This may decrease the number op operations (n_{ij}) to be performed on order and, therefore, the lead time. Another structural possibility to reduce norm lead times concerns changes, or investments, on the shop floor. If, for instance, the firm enlarges the capacity of the perforating unit through investments, than it may be acceptable to reduce the reserved waiting time (w_j) for this unit. Keeping this option open in the design of a production control system is part of *the socio-technical procedural guideline minimal critical specification.*

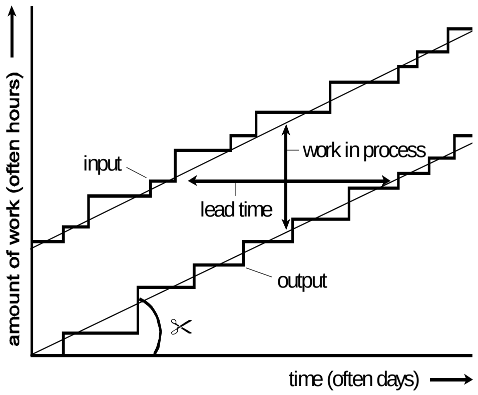

Figure 6 Lead Time Diagram

Actual lead times of orders are strongly related to the work-in-process (WIP) of a production unit. This can be illustrated by a so-called lead time diagram (Figure 6, from Bechte, 1994). The diagonal lines in the diagram reflect the cumulative ‘input’ and ‘output’ of the PU; the gradual change in input and output lines indicates that a number of production hours (required for an order) has come in or is ready for the next PU. The horizontal spacing between the diagonal lines reflects the mean order lead time. The vertical spacing is the mean volume of work-in-process in the PU expressed in production hours. The mean productivity of a PU (in production hours per time unit) is equal to tangent α or the quotient of the mean volume of work in execution and the mean lead time:

$$P = WIP / LT$$

where P is the mean productivity, WIP is the mean volume of work-in-process, and LT is the mean lead time. The mean productivity is also equal to the sum of the effective working hours per day of the machines (or workers) in a PU. In conformity with the formula above, it therefore applies that a certain degree of effective productivity and a mean lead-time require a mean volume of work-in-process. More work on the shop floor will result in a longer mean lead time unless the productivity of the PU can be increased. In turn, a decline in the work-in-process will be accompanied by a shorter lead time. There is, however, always a minimal lead time (see Figure 5). A decline in work-in-process, therefore, may also lead to a worse productivity (idle machines and/or workers).

The relation between productivity, work-in-process and lead times is very basic and has to be seen as a fundamental law (also called Little's Law) for production control. By controlling the workload of a PU, central production control reduces the variations with which PU-control has to deal. This is especially important when variations in the demand are not caused by the PU itself (which is usually the case) or if the PU does not have the means to deal with the variations. Workload control can be seen as an interpretation of *the socio-technical design guideline of variance control.*

10. Production Control Functions

Having defined the production units, the operational characteristics and agreements on lead time, the production control functions can be filled out. The following functions can be distinguished (see also Figure 3):

- aggregate production planning;
- material coordination;
- workload control;
- work order release;
- PU control.

In this particular case, PU control is done within the PUs, work order release is the responsibility of the manufacturing department, material coordination is partly performed by the sales department and partly by the centralized planning department, workload control is the responsibility of the centralized planning department and, finally, aggregate production planning is the task of the management team of the firm. This assignment of responsibilities is in conformity with *the socio-technical design guideline of variance control.* The specific decision tasks will be explained in the remainder of this section.

Aggregate production planning. Aggregate production planning can be regarded as a long-term planning for the goods to be delivered (aggregate delivery plan) and the capacity to be used (aggregate capacity use plan) and adjusted over time (aggregate capacity adjustment plan). This planning specifies the goods to be made on stock and on customer order. It also describes the agreed minimal and maximal stock levels (aggregate inventory plan). The firm in the case study has opted to order raw materials only on stock; the entire production process is based on customer order. Specifying the aggregate production plans, involves further identification of the operational characteristics and the corresponding norm-lead times. By doing so, aggregate production planning specifies the objectives of the decision levels of the remaining production control hierarchy. It serves *the socio-technical design guideline of minimal critical specification.*

Material coordination and workload control. Material coordination is partly performed by the sales department and partly by the central planning department. The sales department submits quotations together with specifications of the dates of delivery. The sales department has to inspect the delivery times for feasibility. In the particular case described in this paper, the planning department suggests earliest delivery weeks for new orders, depending on the overall workload of the factory. If necessary, the sales department may request earlier delivery weeks for particular orders. This can be realized through an adjustment of the productivity of the PUs (see previous paragraph). All this requires co-ordination between the sales, the planning and the manufacturing departments (*socio-technical design guideline boundary location*). Having obtained a final confirmation of an order it may be necessary to check once more the feasibility of the delivery date mentioned in the quotation especially when there is quite some time between quotation and order confirmation. Meanwhile capacity can be reserved if there is a fair chance of an order being accepted. This also requires coordination between the sales and planning departments. The planning department makes the planning of confirmed and expected orders. This planning is based on the norm lead times calculating back from the date of delivery. For each PU an order has an internal delivery time that should be met as closely as possible. By calculating back from the date of delivery (instead of planning an order as early as possible) the capacity available for any short-term orders is extended as long as possible (*socio-technical design guideline minimal critical specification*). Next to this ‘medium’ term planning, the planning department provides a short-term planning using confirmed orders in which the various PUs are loaded to maximally their capacity limit. In case the PUs are under-loaded for the coming weeks, it must be possible to move orders forward. This demands an availability of raw materials for, at least, fast running orders. If it is not possible to load PUs under their capacity limit for some periods in the future, then some measures have to be taken, for example, allowing extra productivity (overtime work, temporary workers, or working in more shifts) and/or subcontracting orders. This requires coordination between the planning and the manufacturing departments (*socio-technical design guideline boundary location*). Material coordination and workload control are closely connected activities and are performed by a planning manager who is also member of the management team of the firm.

Work order release. The work order release function should release orders in conformity with material management and workload control. However, there should also be alertness as to the actual status on the shop floor (e.g. ill people and/or machine breakdown.). Decisions on the necessary measurements can be taken in regular meetings usually held weekly. Examples of measurements are the hiring of temporary workers and the decision of overtime work for one or more days. A planning officer who works in the manufacturing department performs work order release. The meetings are attended by the planning officer, the operation manager, the foremen of the PUs, and the shipping manager.

PU control. The PU foremen are responsible for the detailed scheduling of orders so that the internal delivery times can be met (which are derived from the norm-lead times). In the case study, the scheduling of the perforating machines is a particularly complex one because it has to pay heed to both internal delivery times and sequence relations (the possibility to save on set up time).

The specification of the production control tasks of the management team, the sales department, the planning department, the manufacturing department and the PUs, as described here, is done in conformity with *the socio-technical design guidelines of minimal critical specification, variance control, and boundary location*. Only critical elements are specified at higher decision levels. The decision levels are located organizational levels where appropriate measures can be taken. Arrangements are taken to ensure effective coordination between the levels of the production control. After defining the tasks of each level in the production control, the information system has been adapted in conformity with *the socio-technical design guideline of information flow*. Information should be provided in the first place to the point where action on the basis of it will be needed. Decision support tools may be needed for certain functions in the production control. This refers to *the socio-technical design guidelines of power and authority*, which indicates that decision support tools may be needed to be able to make good decisions, *the multifunctional principle*, which suggests that decision support tools may simplify problems so that they can be solved by more than one employee, and *the principle of incompletion*, which asks for simplicity so as not to frustrate the necessity to re-design, if needed.

The success of the production control system, furthermore, depends on aspects described in the *procedural guidelines as compatibility*, which asks for participation of all people involved in the production control, and *the guideline concerning the transitional organization*, which gives the designer of the production control system a role in the implementation of the system. It may be clear *that the environmental guideline of support congruence* forms another element which may support or frustrate the success of the production control system.

The case study presented here concerns a firm for which a production control system has been (re-)designed. At the moment of design, the socio-technical guidelines were not expressed explicitly. The guidelines were followed implicitly, partly, and sometimes simply not. Also, the performance of the new production control system has not yet been evaluated. The case study, therefore, only serves as a tool to show the possible integration of socio-technical guidelines. It does not proof the usefulness of the guidelines.

11. Resumé

This paper has described socio-technical guidelines for the design of a production control system. These guidelines fit well in the systematic approach to the design of a production control system described in section 5. This is illustrated by means of a case study. Important elements of the approach are the determination of operations, goods flow controlled items, production units, the specification of operational characteristics of the production units, and the concept of workload control. The stepwise approach gives employees the opportunity to participate in the design of a production control system. Its bottom up philosophy, furthermore, supports the idea of autonomous, controllable production units responsible for the major part of the planning, scheduling and control of their tasks. The integration of socio-technical guidelines into the approach is helpful in the design and allocation of production control tasks and responsibilities over the various departments/people of the firm.

An interesting aspect of the approach is the fact that production units are defined on the basis of getting autonomy with respect to production control. The Dutch socio-technical literature (Van Eijnatten and Van der Zwaan, 1998) suggests to design first the production structure, by means of production flow analysis or other clustering methods, and then the control structure. This paper has stressed the need to focus on autonomy with respect to production control. This can be seen as an implicit plea for, at least, a simultaneous design of the production structure and the control structure.

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