Design Wisdom of Production System Designers

Monica Bellgran

Abstract
Efficient production systems are necessary for the realization of products that fulfil customer needs and delivery requirements. Generally, the task of designing production systems belongs to the Production Engineering field. The system design work is, therefore, often managed and performed by production engineers at manufacturing plants with the support of relevant expertise from other disciplines. The paper discusses the production system design process from different perspectives such as how the design work is planned and performed, and by whom. The focus is put on the system designers and how to compose and manage a design team, the impact of the system designers, choice of internal or external designers, and use of analytical and creative abilities when designing. Furthermore, different perspectives and attitudes affecting the system design preconditions are identified and analysed, and the topic of design wisdom is discussed.

1. Introduction

1.1 Background

Although a production system could be seen upon as a product, the process of designing a production system is quite different compared to the process of designing products. Defining the production system only by its technology (e.g. an automatic assembly line or a parts manufacturing cell) makes a generalization to single-unit products interesting from a design perspective. However, when regarding a production system as the combination of a technical and a social system, the design complexity increases dramatically. It means that a production system is not only to be used by humans, but humans are part of the system itself. Having this perspective, the systems view becomes relevant saying that the totality deviates from the sum of its parts. The assumption of reality is hence that the developed knowledge is system-dependent. Another consequence is that the design tasks not only consider the technical parts of the system, but is also related to the design of the social system that should fit to the technical system, and vice versa.

Consequently, designing a production system is a unique and complex task where many parameters should be taken into account during the process of creating, evaluating and selecting the proper alternative. The decision process is also largely affected by contextual aspects such as the attitudes of the involved parts, resources available, the company's priority of the task, and the company culture. These aspects affect the preconditions for the design task that is to be performed by the system designers.

1.2 Research Methodology

The empirical data is collected within studies of ongoing and retrospective system design projects implying collection of data at six extensive case studies and an interview study at another ten Swedish manufacturing companies, summarized in (Bellgran, 1998). Mainly the design process of one type of production system; the assembly system has been studied. The system designers' impact has also been emphasized in the early empirical studies. A model for analysis of the assembly system design process is developed as a result of the synthesis between the empirical and theoretical studies. The model utilises the principle of the 'double-task' of the design process, i.e. planning the design process is one design task, and the actual design activities represents the other task. Ongoing empirical studies within a national research project called "TIME' deals with manufacturing efficiency in terms of disturbance handling on a strategic, tactical and operative level. Empirical findings from these ongoing studies supports the discussion concerning how to take care of the design wisdom of system designers, as briefly discussed in chapter 6.

2. Frame of Reference

2.1 Design Terminology

The term ***design*** tends to be associated with systems, whereas ***planning*** tends to focus on processes (Dandy, 1989). The term design guides the definition used in the research:

> *The design of production systems involves defining the problems, objectives and outlining the alternative course of action (problem-solving), and the evaluation, choices among alternatives and detailed design of proposed production systems (decision-making). The result of the design work is a description (specification) of the production system.*

Along with the definition of the product development process, the term ***production system development*** comprises both the design and the realisation of the production system. To separate the work of practically making different system alternatives from the overall task of designing including problem-solving, evaluation etc., the term ***create*** is used. Create means to make something new or original, according to Collins 1995 dictionary. Design is mainly associated with new production systems, although ***redesigning*** existing systems is often the industrial reality. The work of designing a production system is defined as a ***process*** here referred to as a procedure, a happening or a change in something during a period, along with the Oxford dictionary (1995) definition where process means a series of actions or tasks performed in order to do, make or achieve something. A process should have defined conditions, input and output. Adding the term ***systematic*** relates the design process to a set of rules whereby the system can be determined (Andreasen, 1992), and similarly as being an activity or behaviour that follows a fixed plan or system, so that things are done in a thorough and efficient way as explained in the Collins dictionary (1987). The main purpose of working systematically is to improve the result by improving the way of achieving the result. Planning the design process carefully gives preconditions for designing the production systems in a systematic way, as working according to a structure requires this structure to be set before-hand.

2.2 Research in Design Methodology

Questions in design methodology to be put forward are (Roozenburg, 1995) pp. 29:

> *What is the essential structure of designing?*
> *How should the design process be approached to make it effective?*

The answer to the first question is the task of ***descriptive*** methodology, which means to reveal the methods applied in design through logical structural analyses and empirical research, as well as to identify the needs for methodical support. The answer to the second question is ***prescriptive*** design methodology, which forms an opinion based on descriptive analyses, and recommends, or even demands, the application of certain methods for certain problems. Prescriptive design methodology must also construct new methods if no satisfactory methods are available (Roozenburg, 1995). The descriptive aspects may attract people who are not system designers, e.g. researchers, while the prescriptive aspects often are of interest to system designers. However, it is preferable to consider these aspects equally as they are interdependent. The step from insights obtained in a descriptive manner that become recommendations or prescriptions, may be called the 'is-ought' transition. This is-ought transition can be exemplified as ***'someone observes that in several successful cases, a specific similar working method has been used, and subsequently that method is recommended or prescribed with the expectation that success will also follow in other cases'*** (Roozenburg, 1995). The abstract analysis of design could be found within the area of product and engineering design, for example, by Cross (1993), Roozenburg (1995) and Hubka (1988). In (Dandy, 1989), (O'Sullivan, 1994) and especially in (Wu, 1992) and (Hull, 1994), related issues are found related to production system design.

In design methodology the procedures that designers follow are critically studied, and three important parts of this knowledge are (Roozenburg, 1995): a) Models of design and development processes, b) The methods and techniques to be used within these processes and c) A system of concepts and corresponding terminology. A lot of the related work that has been found concerns methods and techniques to be used within the system design process. The task has often been approached from the prescriptive side instead of starting from the descriptive side. The general complexity of the field is due to e.g. a lack of precise and standardised terminology, several abstraction levels, focus on applications, and focus on tools development.

3. A Model for Describing the Production System Design Problem

The empirical findings have shown the importance of separating the design process from its planning in terms of how it's managed and structured. The design process is further divided into the preparatory design (where the preconditions are analysed and the requirements are specified) and design specification (dealing with the actual creation and selection of the proposal). A developed model the production system design task, applied on assembly systems comprises the three parts illustrated in figure 1, each part including relevant aspects on another level of detail, see further in (Bellgran, 1998).

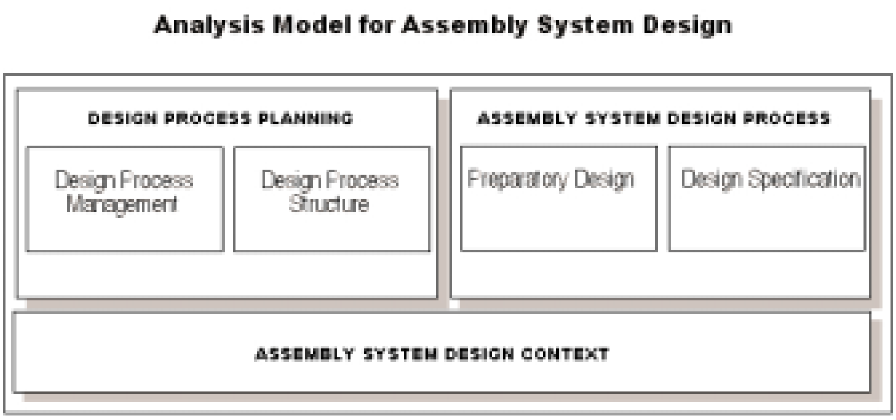

Figure 1 The model illustrates the design process planning, the system design process and the fundamental contextual part (Bellgran, 1998).

4. Designers of Production Systems

4.1 Team Composition and Project Management

The composition of a project team and its structure concerning the management and information flow imposed on the team for effective communication and control, are critical to the management of the implementation of manufacturing projects (O´Sullivan, 1994). As most such projects are complex, the team members should represent a wide cross section of functions and disciplines because no single type of educational background provides the systems knowledge needed to understand the impact of all different factors. Three types of membership can be identified:

- A two-tier membership
- A stage membership
- A division into specialist subgroups

Examples of factors that affected the selection of participants in the system design team in the studied manufacturing companies were e.g. the scope, size and extent of the task as well as the time perspective. Other factors were priority considerations in relation to other commitments and the perspective of the project manager including their options of available competence. A controlling factor was also the expected technology and automation level of the production system, i.e. the more complicated the system in terms of technology, the more extensive participation of system designers (internal and external). Figure 2 shows the of participating disciplines and the membership division in boxes 1 and 2 based on O'Sullivan (1994), founding the empirically identified factors affecting the composition of the system design team (box 3).

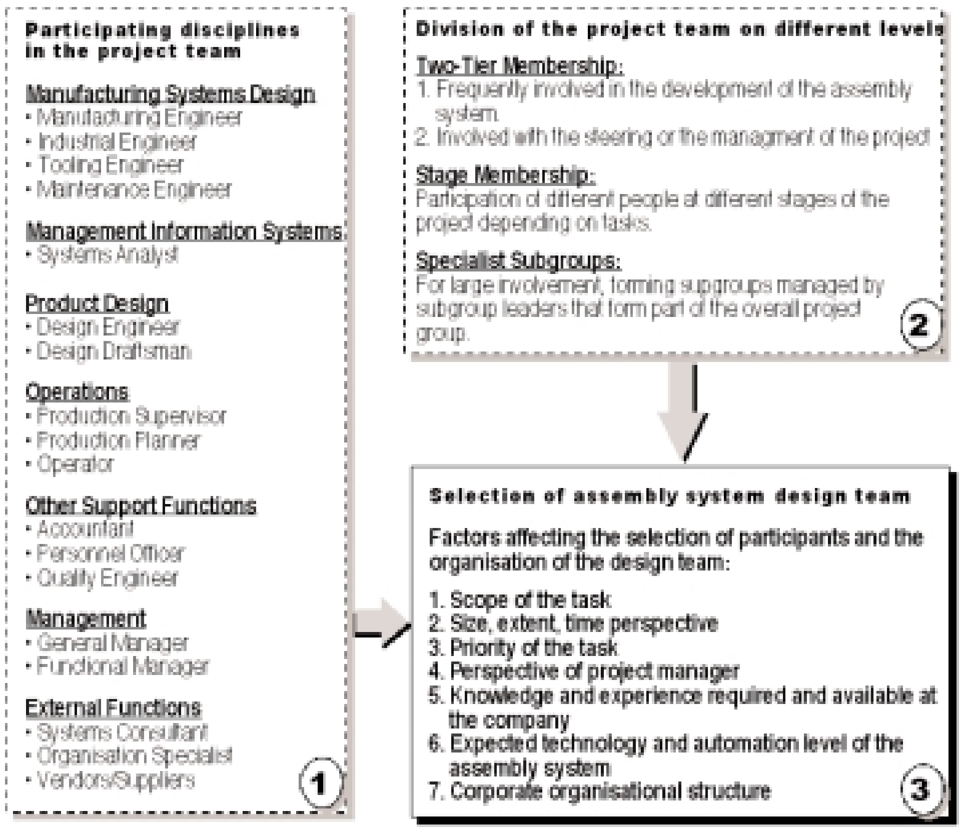

Figure 2 Selection of production system design team is founded on the information presented in boxes 1 and 2, based on (O'Sullivan, 1994). The third box illustrates empirically indicated factors affecting the selection, here applied on the assembly system.

When the project leader and the passionate champion are one and the same, the probability of a successful project is higher. The individual character and abilities of the project leader have large influence on what activities are emphasised, what working procedures are selected, if methods are used etc. according to the empirical findings.

4.2 Production System Designers and Operator Involvement

Generally, personnel from the production discipline and mainly the production engineering department are designing production/assembly systems. This was e.g. the case in the ten studied manufacturing companies (Bellgran, 1995). Here, a typical system design team comprised two to four employees from the production discipline (mainly production engineers), as the task was considered a typical production engineering task. Sometimes they were appointed for the project leadership but in some cases, no formal project team or project leader was appointed. The division of tasks was simply based on the project participants' special expertise areas and positions. The team appointed expertise from other departments when necessary. People from other company functions participated relatively seldom during the whole project.

In the early stages of technology design, there is often a lack of participation by both personnel managers and employee representatives (Karowowski, 1994). However, the operators' contribution is essential for the quality and acceptance of the solution. The possibility and necessity of operator involvement depended on the specific project, the technical complexity of the system, whether operators were to be appointed from the existing organisation or new operators to be recruited. The operator involvement in the ten studied companies as well as in the six case studies was often limited to views upon different system proposals. Specifying requirements, evaluating existing production systems and requirements fulfilments, are other tasks where operator representation would be preferable. However, the operator involvement should be weighted against what is efficient in terms of time and resources and in relation to their ordinary tasks.

4.3 System Designers' Impact

There are numerous mutually influencing decisions that must be made by the system designers, who are permanently occupied with the solution of problems (Bley, 1996). As technical and work organisational developments are being continuously made, there are many options available. As a consequence, the production system design task becomes more complex and the requirements of both the system designers and the design process increase. As indicated by the empirical findings, production engineering is a field that involves actors with different kinds of professional training and expertise. This is due to the complexity of the field, as it is interdisciplinary and covers many different areas. As the knowledge of the production engineers may be quite broad, a holistic approach becomes possible (Granath, 1991).

Apart from people with a specific production engineering background, the production engineers could also have a background as former operators, production leaders, quality controllers etc according to the empirical findings, which also showed that production engineers sometimes change their professional direction towards product design, marketing, purchasing, middle-management of production engineering etc. It was also possible to see a tendency that there is a lack of representation of production engineers with a university degree, and for those, a change of field or working tasks as well as company was not uncommon. One explanation of the situation may be that production engineering involves more tasks of routine or problem-solving character than of production-development character. Because of the manufacturing situation of today, innovation in flexible manufacturing and in product quality is no longer the domain of production and design engineers only. It involves all collaborators in the plant, from design to the shop floor (Karwowski, 1994). Transferring production engineering tasks of routine character to the shop floor is perhaps an efficient way to go to in order to improve the preconditions for production development.

Competence identified by the studied companies to be valuable in order to design a production system were of varying character, such as knowledge about the product, the specific production process, production engineering, equipment and tools, ergonomics and personnel. Experience, common sense and a portion of forward-thinking, were considered important qualities besides having expert knowledge in the field. Technical competence in order to use the computer systems and knowledge of existing supports and tools was also found advantageous. The system designers found it valuable if the team participants knew the production related staff working in the existing production system or going to work in the new system (Bellgran, 1995).

The system designers participating in the ten-company study often worked with other tasks in parallel, which obstructed their possibility of working with the design project in the way they wanted. The common situation was to have a number of projects going on at the same time. The priority matters dealt both with priorities between different projects and priorities between the project and the 'line'. The full utilisation of skilled and experienced personnel, deadlines of projects and other tasks, multi-project involvement of system designers and double project managing roles, and project insecurity due to late investment approval, summarize the priority factors (Bellgran, 1995).

4.4 Choice of Internal or External System Designers

A basic idea when designing any manufacturing system is that systems cannot be fully designed by outsiders (O'Sullivan, 1994). Most systems studied were designed mainly by internal system designers, requiring the necessary knowledge of the system designers, or a wish to acquire this knowledge (Bellgran, 1998). The choice of internal design and realisation also dealt with the desire to own/control the technology, i.e. to develop and maintain system knowledge within the company in order to facilitate efficient running, maintenance and improvement of the production system, see figure 3. Choosing to make the feasibility studies within the company was due to the fact that the identification and analysis of the preconditions and future strategies could be very time consuming and, therefore, either expensive or insufficiently made when external designers were appointed. The same thing is true for the requirements specification. Internal system design also gives a basis for acceptance and knowledge of the coming solution.

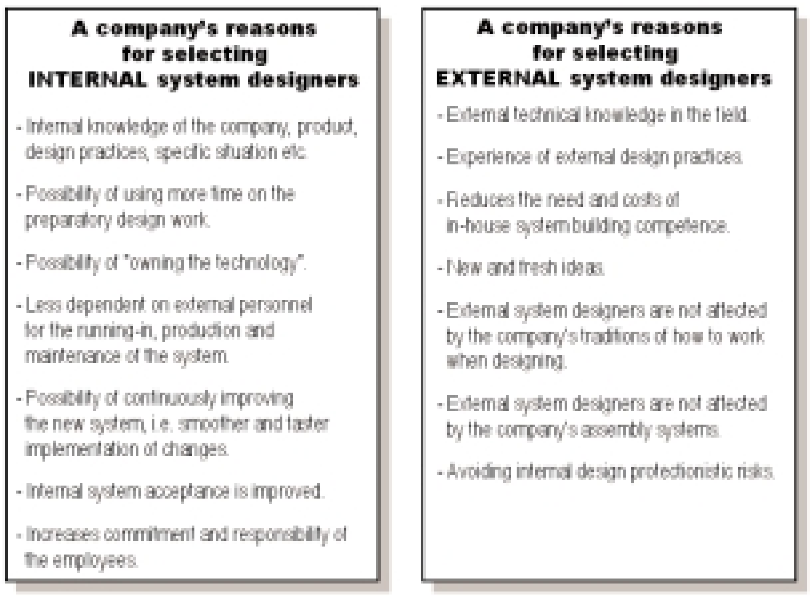

Figure 3 Reasons for selecting internal or external system designers for the system design task (in the perspective of the buying company).

However, there are many advantages in utilising external expertise as well, as the supplier's or the consultant's specific technical knowledge and experience of similar projects can be utilised. A balance has therefore to be struck, both for those that select the project team, and for the system designers themselves to benefit from the routines and experiences at the same time as being able to think in new ways. As discussed further in (Bellgran, 1995), external project participation can be recommended due to the fact that it is easy to become blind to defects in one's own work. When changing a situation, it is easy to be marked by tradition, and the longer one lives with a solution that is not changed increases one's conviction that it is the only possible solution. Summarizing the reasons identified empirically for a company selecting internal or external system designers gives the results as illustrated in figure 3 above (applied on assembly systems).

4.5 Using Analytical and Creative Abilities when Designing

The complete design process involves the utilisation of both creative and analytical thinking. First, a number of possible solutions are generated, then these are progressively reduced as they are analysed and evaluated in more detail until a single, satisfactory solution is obtained (Dandy, 1989). While the analytical thinking is a convergent process, the creative thinking tends to be divergent. Analysing system proposals during their creation process implies preceding the actual analytical phase where a number of alternatives should be evaluated to the same extent, and based on the same evaluation criteria.

Creating a number of system alternatives implies a creative divergent process. The empirical studies have indicated that often the creation of proposals very soon was reduced to only one 'realistic' solution. Although this may be an efficient way to design a system in a short time, it may not utilise all the creativity of the system designers. The disadvantage is that innovative solutions may never even come up due to the unconscious (or perhaps conscious) analysis when the proposals are created. Experience of the system designers is mainly an asset when designing. However, there may always be a risk that the possibilities of thinking in new ways are restricted because ideas are evaluated and analysed too early, based on the system designers' previous experience of what is possible and realistic and what has always been done at the company. This might even be done intuitively, i.e. ideas may be rejected before being formulated in writing or maybe even verbally. Experiences might on the other hand also be a creative source and a foundation for creating conceptual system solutions. The synthesis of different solutions is probably facilitated by a rich experience base to get ideas from.

The risk of obstructing the creative ability of the system designers should also be considered. A view against working systematically when designing, using methods for the purpose, is that it may obstruct the designers' creativity, as indicated in the empirical studies (Bellgran, 1998). It reflects the perspective where methods and structures are looked upon as controlling the design process. However, whether a structure is seen as a support or not mainly depends on the attitudes of the system designers involved. A method may be helpful in supporting associations and leading to new questions, pushing the creative thinking further. It also supports the designers in giving more time for essentials such as creating system proposals, instead of spending a lot of time on structuring the design task. The challenge is, therefore, always to find the optimum between control and creativity that best suits the task of designing production systems.

The utilisation of the abilities of each individual of the design team is also important to consider. A creative thought always arises in a single brain, which has naturally stored up knowledge, experience and impressions from others that are of importance for the new thought. However, it does not make the creative impulse into a collective product (Ekvall, 1988). Although designing production systems in teams is preferable for many reasons, it is unwise not to consider the risks that team work implies for new thinking. Creative people are sometimes badly suited to work in groups because the creative processes takes time and space and this is often not allowed in short design meetings. Creative people may, therefore, avoid active participation under such circumstances. A consequence may be the risk that the new system will consist of conventional solutions. The synthesis, i.e. the integration between different forces within a system design team is, therefore, essential for the system quality (Ekvall, 1988).

5. Perspectives and Attitudes Affecting the Design Preconditions

The empirical findings have indicated that the perspectives of those involved affect the degree of focus that companies put on the system design process and it's planning (Bellgran, 1997), see figure 4. It starts with the managers and their perspectives upon the task, which also has an impact on how the system designers view the task. It concerns the system based on a holistic view or not, if goals and means are mixed up, and if the production output is focused on at the expense of the development activities. The perspectives further affect resources allocated for the task, such as the resources assigned to production engineering and development.

Figure 4 Perspectives and attitudes affecting the design preconditions (Bellgran, 1998).

5.1 Managers' and System Designers' Attitudes

The attitudes of the managers and of the system designers towards the task are contextual aspects that influence the design process. As shown by the empirical findings, the system design process is seldom emphasised and used as an efficient means in order to create the best possible system, and is consequently not always carefully planned either. The task e.g. suffers from being latest in the development chain as it is hard to motivate an emphasis on the coming production system when resources and effort are needed for the product design process.

A person's attitude has a consistently strong relation to his or her behaviour. Influencing behaviour by means of attitude change must consider the degree of correspondence between the behaviour that is to be changed and the attitude at which the influence attempt is directed (Ajzen, 1977). For example, to consider the work organisation when designing a production system is partly a question of attitudes among the system designers. If the goal is to increase the work organisational considerations, this is largely facilitated by a correspondence between the required behaviour and the system designers' attitudes towards it. The same thing is true for the overall ***goal*** of designing by means of improving the ***way*** to work when designing. If this activity or process is to be improved, it requires that the attitudes of those involved are directed towards the same target. In turn, for this to be possible it requires that the managers, system designers and others involved have identified the potential for improvements that this would bring as it always boils down to a question of profitability and survival of the company.

5.2 A Holistic View

The way production systems are designed is based upon how they are viewed. A holistic view implies that the production system should be designed in terms of its technical and physical characteristics, its human resource requirements and organisation of work (Bennett, 1986). With a holistic view, the optimal system is the one that utilises and organises technology and staff in the best way. It also means that the production system should be seen as a part of the totality and not as a limited part, in order to avoid sub optimization. Therefore, it becomes important to consider the contextual aspects.

Both the ten-company study and the case studies indicated that a holistic view was sometimes missing when designing, as the systems were not always seen as a combination of machines, equipment (technical system) and of people (social system). This was especially indicated when it came to smaller systems, where the design process merely became a matter of buying machines and equipment, and of planning the layout. The lack of a holistic view was also indicated when the systems were automatic, as mainly the technical part was considered.

5.3 Mixing Goals and Means

The empirical findings indicated a tendency to mix goals and means, i.e. the design process was not regarded as a means to create the production system, and the planning of the design process was not regarded as valuable means to get an efficient design process. Projects fail mainly because of the design process and not because of the operation paradigm (O'Sullivan, 1994). The reason is probably that the right operation paradigm is not selected during the system design process, rather than the fact that something should be wrong with the operation paradigm.

The ten-company study showed that the design work and discussions on alternatives often started from a layout. Here, layout-planning was often referred to as a goal instead of as a valuable means. Planning layouts implied visualisation of the proposals, which was perceived as a more concrete and result-controlled activity compared to the overall complex design work. Many things are abstract and difficult to visualise on a layout and may be omitted if only the layout planning activities is at focus. The layout should, therefore, be used as a tool supporting the arrangement of facilities instead. How this is approached when designing depends on the perspectives and attitudes of the system designers.

5.4 Production Engineering and Development Resources

The six case studies and the ten-company study showed a lack of available or applied methods to support their system design processes. As the task was not focused on, the interest in searching for, developing and utilising methods was also weak. In general, the overall production engineering resources at a company affect the system design projects in terms of available and competent staff, resources, supportive methods and, not least, the status of the area, which influences priority considerations etc. The production function is often neglected and product development/design may be over-emphasised at the expense of process improvements according to Bloch (1988). While production has not been viewed as an intellectual challenge, its intellectual base has not expanded as the products have increasingly become more complex (Ibid.). A Danish study showed that 79% of the industrial R&D resources in 1981 were used for product development, while only 16% were used for production development. A large part of these 16 % could be related to costs for the running-in of new products, which resulted in a figure of only 9% of the R&D resources that were used for new processes and systems. These figures show a proportion between resources put on production development and resources put on product development that is interesting to analyse further.

5.5 Focus on Production Output

Focus on production output rather than on development activities is another example of a contextual parameter related to the attitudes and perspectives of those involved, which affected how the system design task was approached in the studied companies (Bellgran, 1998). In e.g. two of the case studies, the new system design project subordination to the production output clearly restricted the possibilities of achieving a good solution due to lack of development resources. The general need to solve acute production problems implied that the system designers had less time for new system design activities. As put forward by a system designer in one of the studied companies, the production engineer who solves an acute problem is more appreciated than the production developer who may prevent the problems from appearing at all. The more resources allocated to problem-solving, the less are left to work on a long-term basis in order to eliminate disturbances, which increase the risk of more problems to be solved and so on.

5.6 Analysis for Determination of Design Preconditions

The previous mentioned design preconditions are directly or indirectly a consequence of the attitudes and perspectives of those involved in designing production systems, see figure 5.

ANALYSIS OF PERSPECTIVES AND ATTITUDES AFFECTING ASSEMBLY SYSTEM DESIGN

Determination and consequences of the managers' and the system designers' perspectives and attitudes:	• Is the assembly process regarded as a core activity? • Is the potential of an improved assembly system by means of its design process identified, and/or relevant? • Is the assembly system design task emphasised? • What are the intentions towards the planning of the design work? • What are the consequences of the product design process? • What are the attitudes towards a structured approach? (support/bureaucratic/increases documentation demands) • Are there any differences between the managers' and the system designers' perspectives and attitudes? • Are methods developed and/or used? • Is a correspondence between the attitudes and the desired design activities to be found (directed towards the same target)?
Determination and consequences of a holistic view	• How is the assembly system defined and viewed? • Is the assembly seen as the combination of a social and a technical system (comprising technology, staff and the organisation between these into a whole) or regarded otherwise ? • Is the totality in which the assembly system is a part, considered? • What about the interfaces towards other system parts? • Is the size of the assembly system affecting how it is considered? • Is the assembly principle affecting how the system is considered? • Are there any risks for suboptimisations?
Determination and consequences of mixing goals and means:	• Is the design process separated from the assembly system? • Is the planning of the design process regarded as a valuable means to get an efficient design process? • Is it possible to identify the different sets of inputs and outputs of the design process and the operation of the assembly system? • How is the planning of the layout going to be utilised (goals/means)?
Determination and consequences of production engineering and development resources:	• Are production engineering and production development activities separated (formally/between the staff/towards operator level)? • How are the company preconditions, financial situation, manufacturing strategy, and production process affecting the resources allocated to production development activities? • What about the size, competence, experience, and training of the staff at the production engineering department? • How do the company size, geographical localisation, project time horizon, and attitudes of those recruiting personnel, affect recruitment and retention of production engineering staff? • What resources and supportive development methods can be found? • Are preparatory planning activities made, e.g constructing tools? • Is the proportion of resources allocated to product design and systems design relevant? Is there a balance with respect to input and output?
Determination and consequences of focus on the production output	• Are production development activities, such as system design, obstructed by focus on the production output? What are the consequences in a priority situation? • Are fire-fighting and short-term activities an essential part of the work?

Figure 5Questions supporting an analysis when planning the system design process.

The aspects in figure 5 are summarised in terms of questions supporting an analysis when planning the system design process, here applied on the assembly system.

6. Conclusions - Design Wisdom

Designing a production system is not a subject for the same external pressure of interested parties compared to when a product is designed. However, if an industrial improved output level, efficiency and quality are desired, it is far better to emphasise the means, i.e. the process of designing production systems, than to exercise greater control over existing systems (Bennett, 1986). Designing production systems in a systematic way facilitates a holistic view and the possibility of taking relevant parameters into account. This requires a conscious planning of the design process, the consideration of the contextual factors, and the utilization of the system designers' broad competence and wisdom.

Design wisdom concerns the knowledge and experience of contextual aspects and preconditions, such as those highlighted in this paper, which affects and guides the system designers when designing. Another dimension of design wisdom is the accumulated knowledge and experience of each individual system designers, from successful and less successful system design projects, specific solutions, working procedures etc. The accumulated wisdom of system designers within a company is to some extent captured within the traditions of how to design production systems, which affects new design projects. However, an important question is also how to transfer individual knowledge of a system designer to company-owned or otherwise general knowledge. This could be made by translation and documentation into tools, methods, checklists etc that systematizes and visualizes the system designer's knowledge. It could also be done by different learning programmes for direct transfer to new designers. The difficulty is thus to identify, structure and document the system designers' knowledge. It may, for example, have become intuitive knowledge and understanding for specific problems. It is also a question of time and interest of the system designer as well as of the company in taking care of the knowledge that has been built up by individuals. Today, when organizations become leaner and the specialization of the employee's increases, we can find important motives for utilizing the knowledge built up within a company. These, and related issues are studied further in the mentioned TIME-project in order to improve the preconditions for production system designers in performing successful design projects.

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