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DON'T ENGINEERS CARE ABOUT OCCUPATIONAL HEALTH AND SAFETY?

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1. Introduction

A well-recognized understanding within ergonomics is that engineering design is a strong determinant of usability and industrial ergonomics. Examples are a production engineer who designs new workplaces for operators or a civil engineer who specifies materials and chemicals to be used in construction work. However, engineers themselves do not always seem to be aware that they influence other employees' work environment [3]. Hence, they do not take ergonomics or work environment aspects into consideration in engineering projects. In Denmark, the Society of Danish Engineers recently wanted to elucidate and debate the question of how engineers contribute to the creation of the work environment at Danish workplaces. The society initiated a survey on this topic, which is reported in this paper. The purpose was (i) to elucidate how and how much engineers influence other employees' work environment, (ii) to identify engineers' attitudes towards the work environment, and (iii) to identify their opinions about opportunities and constraints for including work environment considerations in their work. The term 'work environment' is not fully identical with ergonomics or occupational health and safety. When used in the Scandinavian sense, it covers a wide range of impacts of work on human beings, including physical, chemical, physiological, and psychosocial conditions. The concept emerged from national regulation reforms in the early 1970s that resulted in work environment laws in the Scandinavian countries.

This paper first introduces different approaches toward integrating ergonomics into engineering. It turns out that the underlying studies are based on modelling and experiences from a wide range of engineering projects and industries. The object of engineering may be new products (consumer or industrial), industrial processes, factories or buildings or modification of such objects. Different types of industries are represented, i.e. mechanical engineering and process industries. Across the contributions, however, it is remarkable so little efforts are used to relate the background and context of these engineers to their options for integrating ergonomics into engineering. Fortunately, the results from the survey made it possible to investigate the research question: Which significance does the engineering domain, job tasks, organizational position and industrial branch have for engineers' perception of their role and options in integrating ergonomics into engineering? Moreover, the implications for ergonomists will be considered.

2. Constraints and strategies for integrating ergonomics into engineering

Different understandings of constraints and strategies regarding integration of ergonomics into engineering design can be found. An overall distinction of levels can be made between those focusing on the individual engineer and those focusing at organizational factors within the setting of engineering. More rarely extra-organizational factors are considered. It is characteristic of the ergonomics literature that part of it is prescriptive, suggesting strategies without inquire into the problem. Other parts are descriptive, investigating the constraints for integrating ergonomics into engineering projects, and still other parts are doing both.

2.1 The individual engineer

One line of approaches found focus on the knowledge and skills of engineers. As many engineers are not acquainted with ergonomics it is seen as a major strategy to supply them with ergonomics information, principles and data. By transferring ergonomics knowledge and skills to engineers, in a manner in which they can be used, ergonomics can be integrated into engineering [27]. It is often recognised that such information must be 'delivered' in support tools with which the engineer is acquainted, e.g. integrated into CAD systems [19]. It is also studied under which conditions engineers will value and use ergonomics information as it is recognised that such information not always can be used for design [16]. Burns & Vicente [7] point out that design engineers perceive ergonomic information to be of minor importance compared to what it costs to obtain it. Ergonomics standards are seen as another way of transferring knowledge. However, Rogers & Armstrong [25] early recognised that ergonomics standards very often are ignored by design engineers, one of the reasons being that they are formulated in vague and general terms. This is supported by a more recent study of Wulff et al. [32] who stresses the importance of ergonomics design criteria having specific formulations. Wulff et al. also suggest that it is needed to strengthen ergonomics issues in the curriculum in engineering schools.

Another line is focusing on the engineers' attitudes to ergonomics. This covers active resistance to integrate ergonomics considerations [32] to giving low priority to ergonomics compared to other criteria in engineering [3] [30]. Also, pre-conceptions about their role and assumptions regarding their responsibility are seen as a main factor preventing good ergonomic design practice. This attitude may be broken down by feeding back user experiences to the engineer and by "appealing to the engineers' sense of professional and moral integrity" [29]. Willkrans et al. [31] suggest design engineers should spend some time working in the production to get acquainted with the consequences of their design.

A third line takes its departure in the engineers' approaches to the design process. Meister [22] points to some characteristics of engineers' problem-solving process. In general, the engineer deviates from an optimal decision-making process because his work is based on experience. He prefers solutions previously proven to be effective, and he is intuitive in his thinking, often leaving out alternative analysis and behavioural aspects. Wulff et al. [32] also suggest this deviation from a rational model: "The designers in our cases did not assimilate all design requirements and then transform them into an optimal design".

Instead of taking a cognitive approach to the design process it is suggested to look at the character of the design process. Burns & Vicente [8] suggest that the design process is driven by constraints. The solution of a design problem is a negotiation of a constantly changing constraint field. Hence, ergonomists must negotiate their design priorities with those of other designers. The better ergonomists are at solving these design problems, the more impact they will have on the final design.

2.2 Organizational factors

In his pioneering study of neglect of human factors in engineering design Perrow [24] stresses the importance of organization and management. The prevailing beliefs systems of top management and the system of rewards and sanctions are of major importance. According to

Perrow, top management can require that ergonomics information and principles be utilized, and they can structure the reward system so that it encourages engineers to take these principles into account. This stresses elements of organizational politics. Also the internal organization may pose a problem as engineers are insulated from the consequences of their designs. Due to this division of labour engineers do not internalise ergonomics. As a mean to overcome this Perrow point to feed back mechanisms: “If operators participated in design reviews, if designers were brought into contact with experienced operators, or if engineers were required to operate their equipment briefly or even just see it in operation, the externalisation would be somewhat reduced”. In the same line Willkrans et al. [31] suggest that experiences and requests from production personnel in a systematically way must be fed back to design engineers. This can be done by a requirements specification document elaborated collectively by production personnel. Launis et al. [26] stresses that a specific activity as workplace design does not exist in the organization, no one is responsible, and the engineers are technological oriented with lack of work-oriented objectives. A collaborative design process involving different occupational groups is suggested as a strategy to design of workplaces with good working conditions.

Ergonomic intervention in engineering design projects is widespread recommended and reported. According to Cushman & Rosenberg [11] a human factors engineer should participate as a member of the design team with specific tasks in the different phases of the design process. As the concept of concurrent engineering has been widespread in industry this is seen as a possibility for including ergonomists in the cross-functional engineering teams [23] [12]. The role of the ergonomist in engineering projects is debated. In some instances the ergonomist is seen as an expert contributing to the design project based on his or her skills in ergonomics knowledge and methodology. In other cases the ergonomist is reported to have a facilitator role supporting both engineers and operators, ensuring feed back and serving as a communication link between them and management [9]. The facilitator role may even encompass the social construction of the ergonomic intervention and the management of working groups, which will allow a positive confrontation of designer’s knowledge with operators’ knowledge [13]. Large design organizations may hamper ergonomic intervention because it is difficult for the ergonomist to reach all the designers [32].

Jensen [17] argues that the tools for integrating ergonomics are available today. The problem seems to be at the organizational level at which ergonomics need a stronger position. The implication for the ergonomist is to go beyond the traditional role as expert or facilitator, and take on a role as a political agent seeking access to relevant arenas and mobilizing support for the ergonomics agenda.

In another vein of organizational factors the focus is on the lack of a common language between ergonomists and engineers. Therefore education of both ergonomists and engineers to understand each other’s language, terminology and approaches to design problems is seen as a precondition for establishing collaboration between the two groups [14].

Finally, cost and time constraints in engineering projects are observed as factors, which may hinder organizations in taking ergonomics into account [32]. Hence, for ergonomists it is an important skill to be able to “sell” ergonomics to management based on cost-effective arguments [11].

It may be suitable to distinguish between two levels of organizational factors. The first level is the engineering project with its own organizational set up in form of involved actors, management procedures, subculture, and social dynamics between the actors. The second level is the organization of the enterprise, which interacts with the engineering project. This level comprises top management, and overall organizational dynamics including strategic, economic, and cultural aspects. Introducing the engineering project level put more emphasis on engineering as a social process, taking place in teams or networks of engineers and other actors. In fact, within design studies there is a growing focus on the dynamics of team work in engineering design [10] [28].

2.3 Extra-organizational factors

Factors outside the organization are in some ergonomics studies pointed out as constraining or enhancing ergonomics considerations in engineering projects. Willén [30] suggests that the market does not demand ergonomic products and there is no feed back from the end users, which are situated in other firms or are consumers. Slappendel [26] shows how the 'ergonomics capability' of organizations was enhanced through a change in staffing routine leading to first time employment of industrial designers who were trained in ergonomics at a polytechnic school of design. Product strategy related to specific market conditions may also play a role in whether an enterprise builds up ergonomics capability or not. Regulatory aspects, i.e. the European Union's directive on machines or specific national regulation, may also contribute to the enhancement of ergonomics in engineering projects.

2.4 Engineers in focus

It should be noted that across the contributions reviewed, engineers and engineering are treated in general terms, very seldom specifying their professional background, current job tasks, organizational position and industrial branch of their organization. Hence, understanding constraints and options for integrating ergonomics into engineering may be too general for the ergonomist. The survey initiated by the Society of Danish Engineers was aimed firstly at providing empirical evidence of how engineers themselves perceive their role and options in integrating ergonomics into engineering. Secondly, the survey was designed in a way which identified these contextual factors and hence made it possible to make relative comparisons based on these factors.

3. Survey and case study methodology

The study was a questionnaire survey based on 680 engineers in twenty Danish enterprises. The twenty enterprises were selected from five important areas of engineering: electronic industry, mechanical engineering, chemical industry, civil engineering, and public service organizations. Four enterprises were selected from each area. In five of the enterprises, one from each engineering area, engineers and members of the compulsory joint safety organization were interviewed. The questionnaire consisted of 35 close-ended questions. Prior to sending out it was pilot tested by three engineers and adjusted according to their comments. The overall response rate to the questionnaire was 65 varying considerably between the enterprises (25 to 100 per cent).

The twenty enterprises were medium seized compared to Danish circumstances. It was a selection criterion that the employment of engineers exceeded twenty. It is, however, important to have in mind that the enterprises do not have a number of ergonomists employed. Ergonomics or work environment is embedded in the safety organization, often with a single full time safety manager. Additionally, most of the enterprises were affiliated to a local occupational health service from which they could draw on the consultancies of work environment professionals.

3.1. The respondents

The population of 441 responding engineers included chemical engineers (10 per cent), electronic engineers (23 per cent), mechanical engineers (21 per cent), production engineers (3 per cent), civil engineers (33 per cent), naval architects (3 per cent), and planning engineers (3 per cent). The distribution by sex was 91 per cent males and 9 per cent females. The mean age was 41 years. Although the sample were not selected on the basis of representative criteria it turned out to match the member profile of the Danish Society of Engineers regarding distribution of sex, engineering specialisation and type of engineering school.

Around 50 per cent of the responding engineers occupied a management position, usually head of department, project leader, or group leader. The most frequent engineering tasks included projecting and planning, executive duties, supervising and inspection, design and development, and specialist tasks as seen in Fig. 1.

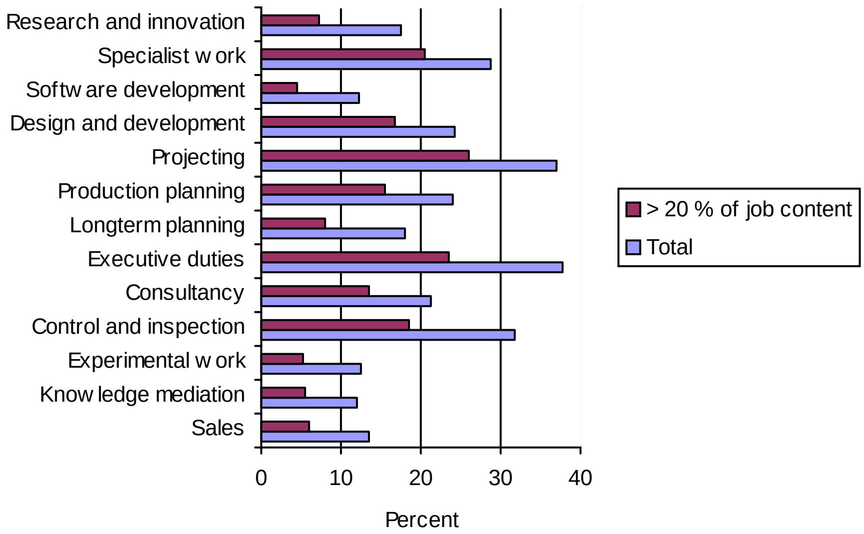

Figure 1. Distribution of job tasks in engineering (n = 441) (max. three marks)

In order to elucidate what sort of tools and communication that is important when carrying out engineering tasks, the engineers were asked which ‘tools’ they were most likely not to do without. As shown in Fig. 2 dialogue with other employees at the enterprise was by far the most important followed by personal computers and dialogue with customers. Technical standards, handbooks, and journals only played a minor role.

The communication patterns of the engineers are shown in Fig. 3. Finally, fifty-two per cent of the engineers had studied work environment at engineering schools. For more than three fourths of these, the hours of education had been less than 50.

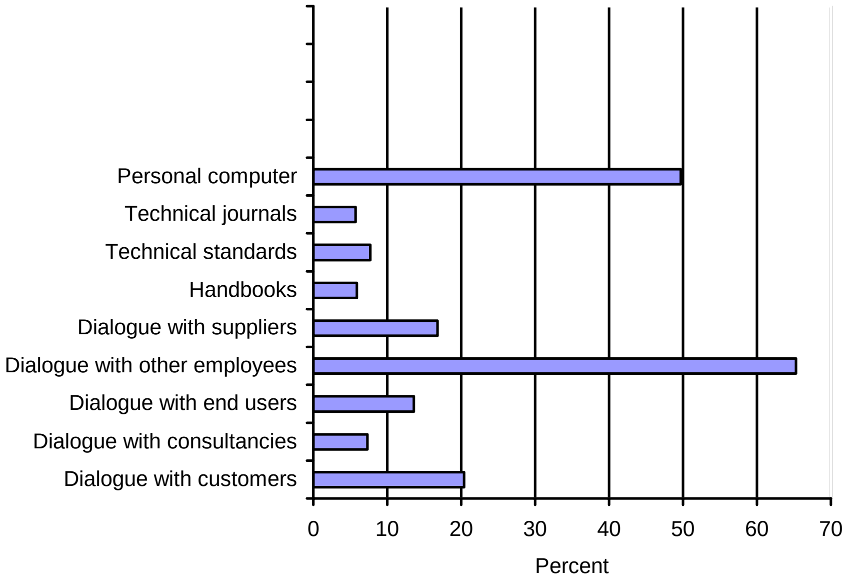

Figure 2. Ranking of 'tools' in engineering (n = 441) (two marks)

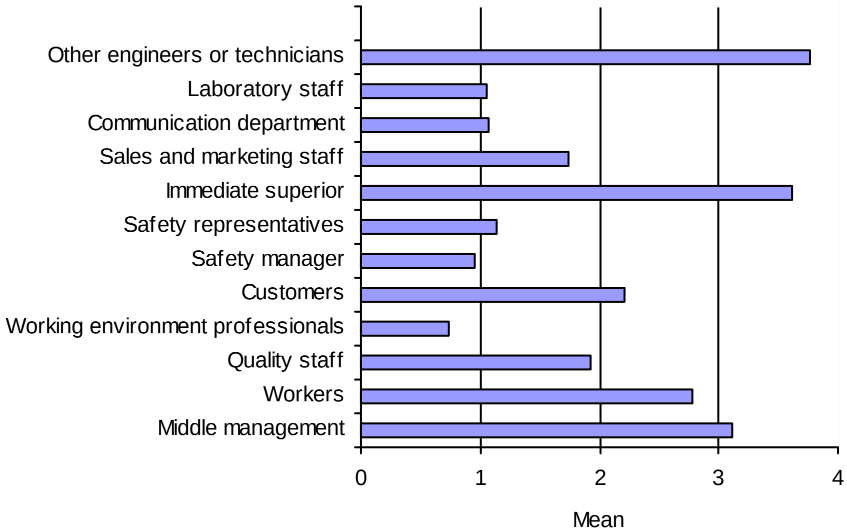

Fig. 3. The communication pattern of engineers in a scale from 0 to 4. The higher value the more frequent communication.

4. Results of a survey among Danish engineers

4.1. Engineers' perceived influence on the work environment of others

The engineers were asked to rate their perceived influence on the following ("no influence" was estimated at 0 and "great influence" at 3): Selection of substances and materials (mean 1.8), production methods and processes (mean 1.5), organization of others' work (mean 1.6), and design of others' workplace (mean 1.1). In certain engineering 'domains', the rating of influence was considerably higher. Engineers indicating their present engineering domain to be placed within mechanical, civil, or chemical engineering all rated their influence on substances and materials to be greater than two. Also, within the chemical domain, the influence on production methods and processes was rated greater than two. Engineers with a high task content of projecting and planning, and supervision and inspection also rated their influence on substances and materials greater than two. Engineers with a high task content of production planning rated their influence on organization of others' work greater than two. Finally, engineers occupying managerial positions indicated a rate higher than two for their influence on substances and materials, and the organization of others' work.

In another question, the engineers were asked to rate their perceived influence on a number of work environment impacts on other people's work. Most of these ratings were between none and little influence. This indicated that engineers in certain domains and with certain tasks were not particularly aware that they made decisions that influence the work environment of other people. In many instances alternative decisions presumably could have been made to the benefit of the work environment of other employees or users of products and systems. Engineers in the chemical industry turned out to be most aware and engineers in mechanical engineering to be least aware. Looking at the engineers' present working domain it was significant that those working in production were more aware of their influence on others' work environment. Quite the opposite applied to engineers working in the domain of chemistry and electronics. Overall these findings suggested that the most important determinant of work environment awareness among engineers was the present working domain and not the original engineering specialisation.

4.2. Engineers' attitudes towards work environment

Five criteria for problem solving in engineering were listed in the questionnaire: comply with specifications, profitability, comply with deadlines, work environment, environment, and quality. The engineers were asked to rate the importance of these criteria in their problem-solving activities on a scale from one to five. The results were distributed on the five engineering areas. Quality (range 3.9 – 4.2) and complying with specifications (3.8 – 4.1) were the most important criteria and work environment (2.9 – 3.5) the least important. The engineers were also asked how management, in their opinion, rated the five criteria when judging the engineers' problem solving. Profitability (3.8 – 4.3), complying with deadlines (3.7 – 4.3) and specifications (3.8-4.6) were the three most highly rated, whereas work environment (2.8-3.4) was significantly the lowest rated. No significant differences between engineering areas were observed. This indicated that engineers in general felt no pressure or expectations from management that they should consider work environment as a part of their work tasks.

Engineers' familiarity with the work environment management of the enterprise seemed to be very limited. Thirty two per cent was aware of the existence of an enterprise work environment policy and they did know it. In the chemical engineering area, however, this figure was nearly sixty per cent. Twenty nine per cent was aware of the policy but they did not know it. Thirty three per cent did not know if the enterprise had such a policy whereas 7 per cent answered no.

4.3 Constraints to considering work environment in engineering

The engineers were asked to mark the three most important constraints to integrating work environment in engineering.

Table 1. Ranking of constraints to the integration of work environment (WE) considerations into engineering (n = 441) (three marks)

Type of constraint	per cent
Lack of time	44
Lack of work environment knowledge	44
Lack of methods and tools to integrate WE	40
Customers do not demand products which are produced friendly to the work environment	28
Management does not appreciate WE considerations	17
It is difficult to use the authorities' recommendations	17
Management are not committed to WE	15
There is no tradition for doing so in the organization	13
It is troublesome	11
It is not required by the authority	7
The safety organization does not ask for it	6
The subject does not have my interest	5

According to Table 1, there was a distinct top three, which indicated that engineers perceived integration of work environment considerations to be quite time consuming. This was rated even higher (52 per cent) if the engineer holds a management position. Engineers believed they lack work environment knowledge, and they were not aware of methods and tools with which to enhance work environment considerations. Lack of time and missing customers' demands of work environment criteria were significant in civil engineering while in mechanical engineering it was management that does not appreciate work environment considerations. Finally, engineers who were primarily engaged in research and development pointed to lack of methods and tools as an important constraint.

The effects of work environment training at engineering schools seemed to be very limited. Engineers with such training rated the lack of methods and tools a bit higher than the mean of all respondents, and they had the same low rating of the work environment criteria in problem solving.

4.4 How to enhance work environment considerations in engineering

Table 2 shows the engineers' ranking of different types of strategies to enhance work environment considerations in engineering. The engineers' assessed more work environment knowledge to be the most essential prerequisite followed by more time and a policy statement from top management. Engineers in public service organizations are much keener than others on integrating work environment into quality and environmental management systems. The chemical engineering area is distinctive in pointing to a dialog with workers as a prerequisite for enhancing the integration of work environment. This area and the mechanical engineering area also separate in wanting work environment factors articulated as technical specifications.

Table 2. Ranking of strategies for integrating work environment (WE) into engineering (n = 441) (three marks)

Type of strategy	per cent
Solidify my knowledge of work environment	53
More time	32
A policy statement from management	29
Integration of WE into the quality or environmental management system	23
Increased contact to WE professionals	18
An enterprise WE policy	17
Technical specifications	15
Dialogue with workers	14
Computerized WE information	11
Access to WE checklists and books	8
Improved contact with safety organization	7
WE efforts are included in the organizations' reward system	5
More frequent inspections from Labour Inspection	3

Engineers' motivation for solidifying their work environment knowledge seemed to be rather high. Fifty per cent wished to participate in continuing education courses during working hours. They found that the most important way for engineers to solidify their work environment knowledge was a course on the particular work environment of their enterprise. Training in work environment management and regulation was valued very low. Engineers with a high content of research and development tasks were the least motivated for continuing education.

Four out of five respondents found that work environment should be a mandatory subject on engineering school curriculum. The respondents had different views on the best way to teach work environment at engineering schools. Forty per cent preferred field courses on identification and evaluation of the work environment in an enterprise. Another 40 per cent wanted work environment aspects to be integrated in relevant technical courses. Only 10 per cent advocated a course on work environment regulation.

The motivation for continuing education courses are considerable higher among engineers employed within the construction and production area. Managers are slightly more motivated than non managers. Engineers within research and development are least motivated for continuing education.

In the enterprises where engineers indicated that work environment was integrated into the quality or the environmental management system, the only significant difference was a more comprehensive knowledge of the enterprise work environment policy. Work environment criteria in engineering were rated as low as in the sample. In spite of this, the engineers considered such integration a valuable prerequisite to enhancing work environment considerations.

5. Discussion

How does the survey among Danish engineers add to the body of knowledge of constraints and strategies for integrating ergonomics into engineering? First, it indicates that we need to differentiate the entity 'engineer'. Engineers have different background and their 'sensitivity' to ergonomics depends in some degree on their current engineering domain, task content, their position in the organization, and the industrial branch of their organization. Second, the engineers' views on constraints and strategies were identified, taking into account the limitations of the questionnaire method. How do the viewpoints of engineers relate to the constraints and strategies described in paragraph two?

5.1 The individual engineer

It seems that the survey confirms that work environment knowledge is a crucial factor for the engineers. Computerized work environment information, however, are valued low by the engineers even if the pc is one of the most important tools for them. Further, the survey demonstrates that work environment in the engineering curriculum does not have any effect on the engineers' awareness and attitudes to considering such. This indicates that work environment knowledge does not automatically imply action. There may be several explanations for this, e.g. the scanty extent of work environment courses and their quality. It may also, however, point to that organizational factors restrain the active use of such knowledge. The low rating of work environment criteria among engineers with work environment training indicates that the socialization in the enterprises plays an important role. During our interviews, we often observed a more positive attitude towards work environment among younger engineers than among their elderly colleagues in management positions. Interviews with engineers also revealed that it is not just a low rating. Confronted with questions how to handle a work environment problem the engineers were confused about their role and responsibility, and they did not know how to handle such a problem in the organization.

The survey indicates that engineers in general are not aware of their influence on other peoples' work environment. In line with Perrow [24] this may partly be explained by the isolation of engineers to certain part of the organization, often socially and organizationally separated from users or operators. In large enterprises, they may be working in highly specialized work groups, making it difficult to see the work environment consequences of their efforts. But even in medium seized enterprises we observed the isolation in spite of spatial vicinity. The communication pattern shown in Fig. 3 reveals the very limited contact between the engineers' world and the formalized management system of work environment in Danish enterprises. This is also found in other studies [3] [4].

The "lack of time" constraint is difficult to interpret. For the individual engineer, however, it may express that he or she is in a situation with many tasks and deadlines to be met. In such a situation the individual engineer will consider work environment aspects as just another task or constraint, which will impede his work. The constraint, however, may also be seen as a way of making it legitimate to do nothing, and hence reflects the very limited role attributed to work environment by the engineers.

The engineers express quite a positive attitude to the statement that work environment aspects should be considered by persons (engineers) who design, plan or implement. Related to their low awareness and rating of work environment it seems to be an 'espoused theory' and not a theory-in-use [1].

5.2 Organizational embedment of engineering

The low rating of work environment criteria in engineering may be caused by the similar low rating by management, hence giving support to Perrow's emphasis on management belief systems and organizational politics.

Time constraints, however, may also be due to conflicting criteria and interests in engineering. As stated by a construction engineer: *"In a construction site you do not need an ideal shuttering, you do not need an ideal reinforcement, and you do not need an ideal casting because every one of these will spoil something for the others. You need a compromise, the most appropriate shuttering that will allow the most appropriate reinforcement that will allow the most appropriate casting. It is always a compromise, but today the shuttering company does not consider the reinforcement activity"*. This point to the importance of different individual and organizational interests and professional perspectives on the design object.

In spite of they overwhelmingly prefer dialogue (with other engineers) as a "tool" in their daily work engineers mainly point to solidifying their knowledge in the area combined with management policies and systems as the means to enhance such considerations. In contrast, engineers did not regard a direct dialogue with workers and members of the safety organization as a means to enhance work environment considerations. This may be explained by the fact that engineers - instilled in them from engineering schools - prefer rational and systematic systems. Policy statements and standards from management are in line with this approach. Finally, engineers do not like the whip as motivation mechanism. Work environment efforts should not be part of the reward system and the Labour Inspection should keep away from engineering projects, cf. Table 2.

An overall interpretation of the survey seems to indicate that engineers are not aware of the work environment aspects, and they feel no responsibility since neither management nor the safety organization explicitly express expectations on that subject. They primarily point to individual and organizational strategies, which in the least way interfere with their engineering tasks and responsibility, e.g. system integration and management policies. However, they have an espoused theory that work environment aspects should be integrated in engineering, and they are open minded to continuing education in work environment, especially those with high job content of production and planning.

5.3 Perspectives for integrating ergonomics into engineering

Combining newer literature on engineering design and the results of the Danish survey stresses the importance of a more differentiated understanding of organizational factors than the one presented by Perrow [24] in order to understand constraints and develop new strategies for integrating ergonomics into engineering.

What are the implications for ergonomists or work environment professionals if engineering projects are described in terms of subculture, organizational politics, constraints, negotiation processes, and capability? Many ergonomists are involved in different sort of intervention in engineering projects as indicated in paragraph 2.2. Ergonomics interventions are often described as either the 'delivery' of ergonomics expertise or facilitator competencies. The notion of 'change agent' [6], however, may be a more appropriate designation of the actual activities undertaken by ergonomists. The point is, that many ergonomists act as change agents within organizations' engineering activities but this action is seldom subjected to systematically reflection on which competencies is appropriate and necessary. Operating effectively within complex engineering projects embedded in a specific organization require an understanding of the dynamics in organizational change and the social processes unfolding in engineering projects [5]. Badham & Ehn [2] suggest that the key role of ergonomists is to be able to transcend the boundaries between participants from the different 'social worlds' involved in the design process. In order to do so they must "have an ability to understand and sympathize with participants from the different scientific, technical and social design, and user worlds, and create local languages, cultures, and artefacts that enable these participants to communicate and cooperate sufficiently to achieve a successful system design" [2, p.69]. The ergonomist becomes an actor himself in the organizational politics and he must have the skills to navigate and act in such an environment in order to effectively promote the integration of ergonomics into engineering. Ergonomics expertise alone is not a guaranty for this.

6. Conclusion

The survey among Danish engineers indicates that transferring ergonomics knowledge to the individual engineer does not alone 'activate' them to integrate ergonomics into engineering. Organizational factors such as socialization into specific engineering subcultures and the social nature of the design process are decisive in understanding the conditions for integrating ergonomics. Engineering is a complex, heterogeneous activity involving technical and contextual constraints. The latter, which is essentially social constructed and hence derive from the different actors involved in engineering projects, may comprise ergonomics issues depending on the ergonomics capability of the specific organization.

The role of ergonomists may be to enhance this capability by identifying and developing ergonomics resources in the organization, and developing communication linkages and interpretive structures. In doing so, it is important to acknowledge that engineers are widely different. They have different background and 'sensitivity' to ergonomics depending on their current engineering domain, tasks, organizational position and the industrial branch of their organization. Taking that into consideration and understanding the engineering culture in specific organizations may provide a good take-off for trying to change that culture to become more open to ergonomics. This will call for the ergonomist to master the role of change agent, being able to navigate as an actor in the political processes taking place within the organization, including winning access to the early engineering design stages.

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