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Causes of Defects in Construction

- a study of seven building projects in Sweden

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Abstract
This paper is based on a study of defects and defect costs in seven building projects in Sweden. Special observers collected information on 3000 defects found on site. The causes were primarily ascribed to the individuals' actions, knowledge, information and motivation. Lack of motivation was found to be the most common cause.
Almost 100 interviews were made with key persons in the projects to find the underlying causes of defects. The causes were mainly found in how the project organisation was structured. Unstable organisations were found to create uncertainty. Four types of organisational instability were identified; gaps in vertical relationships, gaps in horizontal relationships, organisation not created in time, and changes in the organisation.
The current market situation caused large time and cost pressure. It influenced how the organisation was structured and how the individuals were acting.
Individual causes, as well as organisational causes, are discussed.

Key words: Defects, causes of defects, human error, motivation, organisational instability

1 Introduction

Besides external demands, the principal driving force behind improvement is knowledge of the improvement possibilities. Knowledge of where defects occur is necessary in order to focus upon where improvement measures are most effective.

The study concerns defects found on construction sites during production. Their causes can however be referred to other project phases. The main aim is to find possibilities to improve the construction process. The practical aim is to elucidate the size of defect costs and the causes of the defects. The theoretical aim is to increase the knowledge of why defects actually occur.

The study is performed in cooperation between the Department of Building Economics and Construction Management at Chalmers University of Technology and "R&D West", a regional working group of construction companies in Sweden. The study is a continuation and deepening of a study carried out in 1986-90 by the same R&D group (see Augustsson *et al*., 1989, Hammarlund *et al*., 1990, Josephson, 1990, and Josephson, 1994). In this paper the causes of defects are discussed.

2 A model

According to Gryna (1988), cause is defined as a proven reason for the existence of a defect. Often there are several causes of the same erroneous action. There may be either combined causes, or a chain of causes. For this reason, the term "root cause" is used to describe the most basic cause of an undesirable condition. If the root cause is eliminated or corrected, this will prevent the recurrence of the defect (Dew, 1991, Wilson *et al*., 1993).

Organisations consist of individuals who cooperate with a specific aim. Therefore, it is natural for the defects to be ascribed to individuals (Matousek, 1985, Hammarlund *et al*., 1990, Nowak, 1992, CIB, 1993). It is generally believed that lack of knowledge, lack of information and lack of motivation cause defects. Carelessness is stated to be the most common cause (Bonshor and Harrison, 1982, Matousek, 1985, NEDO, 1987, Hammarlund *et al*., 1990). Lack of knowledge is often mentioned as the second most common cause of defects, but information is also often mentioned. This type of causes is called direct causes because this is the first type you encounter when analysing a specific defect.

However, every action by an individual is influenced by organisational or environmental conditions. Therefore, the root causes can be found in organisational phenomena and in the organisation's environment. This is called underlying causes (see Josephson, 1994, and Atkinson, 1998).

The individual

If individuals are to find it worthwhile to act at all, motivation, expectations and commitment are necessary (Brunsson, 1985). Motivation is people's desire to contribute, through their own actions, to the resultant organisational action. Expectations imply that individuals believe that their actions will result in an organisational action. Commitment means that, in order to achieve something together, people must have some "control" over one another, i. e. they must be able to rely on certain types of behaviour and certain attitudes in the other team members. This control is secured by the creation of mutual commitment. Henceforth, "motivation" will here be used to describe the sum of these three conditions.

Motivation alone is not enough. If an individual is to act correctly, on the basis of his own prerequisites, the individual must also have the necessary knowledge and the necessary information for the specific task. Knowledge is information about and understanding of a subject which a person has in his or her mind or which is shared by all human beings. Knowledge includes skill and experience. Skill is the knowledge and ability that enable a person to do something such as a job, game, or sport very well. Experience is knowledge or skill of a particular job that has been gained during a long period of working on the job. Information about the operation is received in communication between individuals or between organisations.

Motivation, knowledge and information are mutually dependent (Josephson, 1994). For instance, insufficient information involves lower motivation.

The concepts of risk and stress are central in the analysis of causes. Calculated risk means a conscious probability of defects. Higher calculated risk means that a higher probability of defects is accepted. Stress seems characteristic of temporary organisations. Stress is the general reaction of an organism, which is triggered when the individual is threatened (Söderberg, 1979).

The organisation and its environment

The individuals do not work alone. They work under the influence of (other individuals in) the own organisation or (individuals in) their environment. Leavitt (1978) describes organisations as multivariate systems, consisting of four groups of interacting variables.

- Social structure concerns the organisations' sub-system of communication, responsibility, authority, status, rewards and task-oriented procedures.
- Goal includes the organisational goals and all work that has to be done to reach the goals.
- Members concern the people in the organisation and the relation between them. A member can be an individual or a group of individuals.
- Technology concerns the companies' tools for problem solving, including the place of work and equipment as well as programs to organise and direct the work.

However, organisations are not self-sufficient, they are dependent on the environment in which they act. They live in a specific physical, technological, cultural and social environment to which they must adapt themselves.

Together, these five interacting groups of factors define the information and the expectations, goals, attitudes and assumptions, which the individuals use in their actions. It is no use analysing organisations without considering all these factors. The description shows the complex system of an organisation. The underlying causes of defects can be identified in the interaction between these factors.

3 Method

The study comprises an analysis of seven building projects, performed by different companies. Each of these had specific prerequisites, which in a crucial way influenced the process. They were chosen with the intention of acquiring knowledge about different types of projects; product type, contract form, size, time, geographical site etc.

The methodology of the study has been discussed in Josephson (1998). The analysis of the direct causes is both qualitative and quantitative. It is based on mapping of defects that have occurred. Seven observers continuously followed the activities on one site each. They had no other task than to describe defects that occurred. For each defect they analysed and described its causes. The analysis of causes is made in cooperation between the observers and the people involved in the specific defect.

The analysis of underlying causes is qualitative. It is mainly based on open interviews with 92 "key persons", approximately 10-15 per project. They were: 8

client representatives, 11 architects, including interior architects, 5 structural engineers, 8 installation consultants, 9 project managers or assistant project managers, 7 site managers (with full responsibility for the site), 7 foremen, 12 construction workers, mostly their representatives, 16 sub-contractors, managers as well as workers, and 1 materials manufacturer. Specific interviews were made with the observers. Each interview was made personally and lasted 30-90 minutes. They were tape-recorded and transcribed verbatim.

4 Direct causes

In most situations the individual who gave rise to a defect had the necessary knowledge and right information for the specific task, but he suffered from lack of motivation. Half of the total defect costs were classified as lack of motivation. More than ¼ of the defect costs were caused by lack of knowledge and 1/8 by lack of communication, while a small part was ascribed to stress and risk, Figure 1. The distinction between these groups is naturally very difficult, which means that the results should be used with caution.

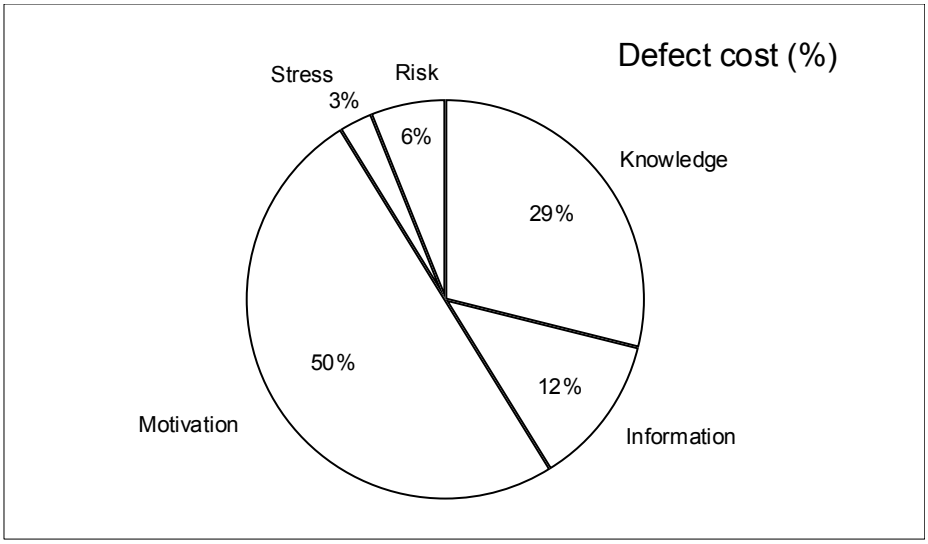

Figure 1: The direct causes (% of total defect cost).

Motivation

Motivation is here used to denote three mutually dependent concepts; motivation, expectance and commitment. The stronger the motivation, expectance and commitment, the more probable it is that the action is the right one.

In the study it was not possible to judge whether the defect was caused by lack of motivation, expectance or commitment. However, it was possible to form an opinion of which level of motivation the individual had when he/she acted erroneously in the specific situation. The mistakes were considered to occur in either of three levels of motivation.

- "*Forgetfulness*". Defects made unintentionally and unconsciously, for instance forgetfulness and temporary inattention. 55% of the defects caused by lack of motivation belong to this group.

- "*Carelessness*". Defects made unintentionally and unconsciously, but without necessary care. Carelessness and thoughtlessness amounted to 40% of the motivation defects.
- "*Conscious defect*". Defects made intentionally and consciously. Theft and damage by non-employed people belong to this group. 5% of the motivation defects belong to this group.

The conception of motivation implies that defects are made intentionally. However, the study shows that just a few defects are intentional and that they are caused by non-employed people.

Knowledge, information, risk and stress

The knowledge defects were classified into three sub-groups; lack of knowledge, lack of skill and lack of experience. More than half of the defects were due to lack of knowledge, ¼ to lack of skill and 1/7 were caused by lack of experience. The distinction between these is difficult to make.

12% of the defect cost could primarily be ascribed to lack of information. Information errors can explain many motivation errors.

Stress and shortage of time characterise building projects. However, only 3% of the total defect cost could be ascribed to this cause. Shortage of time can be an underlying cause of motivation errors and information errors.

Causes per actor

Large amounts of defect costs could be ascribed to design, production management and workmanship. The direct causes varied for these groups of actors, Table 1. Among design defects, lack of knowledge was most common followed by lack of motivation. For defects in production management, lack of motivation was most common followed by lack of knowledge. For defects in workmanship, lack of motivation dominated.

The results reflect each group's work tasks. Design is knowledge-intensive and requires communication. Production managers have varied tasks. Their workload is often heavy and stressful. Workmanship sometimes involves similar tasks over a long period of time, which can explain why knowledge and information errors are rare.

Table 1: Direct causes of defects in design, production management and workmanship.

Cause	Design	Production management	Workmanship
Lack of knowledge	44	34	12
Lack of information	18	11	6
Lack of motivation	35	42	70
Stress, shortage of time	2	5	1
Risk	1	8	11
Total	100 %	100 %	100 %

5 Underlying causes

The most important issue is, however, what the underlying causes of defects are. What factors explain the direct causes presented above? Why does lack of motivation dominate? Irrespective of how you answer these questions, there are many mutually dependent factors, which together form a complex pattern of causes.

5.1 Time and cost aspects

The project time tends to be shorter and shorter within Swedish construction. In most of the studied projects the client stressed the importance of finishing the project in time. Reasons given were for example financial matters or that other activities would be starting such as a school term.

At the time of the study there was a recession. Due to fierce competition both designers and contractors felt forced to accept the short contract times, which led to stress.

> "One consequence of the time pressure was that there were gaps in the brain work, that we didn't think the project properly through." (Architect)

In several projects it was necessary to increase the team of workers in order to finish in time. As a consequence of this, the planning became difficult, and several categories of workers had to share the same areas.

Due to hard competition, all projects were purchased at very low prices. For instance, several designers were payed as low as half of the "normal" price for their jobs. All actors involved were put under hard pressure. This pressure was transferred along the chain of actors.

The contractors had to force the price of materials and sub-contracts down. In several cases it gave negative results.

> "The cost pressure is total. We have left an offer, which is lower than the prime cost. The (specialised) purchasers experience this more. You have to set a ceiling, which they must not exceed. We work with our noses just above the water surface..... It's a success if you break even."
> (Assistant project manager)

> "Maybe you nag at the personnel on site a little too much: 'Think over this!' It means that you maybe press sub-contractors and suppliers a little too much sometimes, reducing the quality unconsciously.... ."
> (Assistant project manager)

The site managers became forced to scrutinise contract borders and machine use. There were clear signs of stinginess.

> "The main office is pushing us to be very careful to check everything we do." (Foreman)

> "Now we must be even more able to find out things which become cheaper and simply to be more stingy....." (Site manager)

This caused pressure on the construction workers. In some projects the site management economised on machines and other equipment.

> ”We would very much like to have a lift. I have never been at a site with more than two storeys, which has not had a lift. We normally go up and down by lift with material ourselves, but here we run up and down the stairs like idiots”. (Worker)

> “We very often hear how bad the project economy is, and they send back every little tiny machine as fast as possible because it costs money.” (Worker)

The situation became even more pressed by the client’s expressed demands on cost savings. The search for cheaper alternatives required considerable effort, for instance of the part of the designers.

> “I have designed a lobby completely finished. Everything was completely analysed according to standard, types of stones, types of surfaces etc. Then one day they called me and said that it will not be a stone floor, it will be a wooden floor instead. I was asked to redesign the stone floor to a wooden floor preserving some parts in limestone. After approximately ten days I had to redesign everything to limestone again. Because they had found a limestone which was cheaper than the wood.… so I have designed three different floors”. (Architect)

It is obvious that short project times and forced down prices have a considerable influence on the individual’s behaviour and therefore also on the process and the defect cost.

5.2 Organisational aspects

Most underlying causes can be ascribed to organisational conditions.

Client’s lack of ability in decision-making

Many actors experienced the lack of ability in the client organisation to make decisions. This led to much irritation on site. There was a clear wish for stricter control, better routines for decision-making and a clearer division of responsibility.

> “You have to control the brief and design process hard. You should be very resolute and demand answers at specific points in time, because you can’t keep on discussing forever. The (client’s) project manager must accept a discussion until a certain point in time and then the decision must be made.” (Clients project manager)

> “You realise more and more that the routines of making decisions must be very clear. You can never be too careful concerning how to divide the project, to specify and come to an agreement about what to do and which standard we should achieve.” (Architect)

The lack of ability to make decisions is often due to lack of competence in the client organisation. Additional causes are instability in the organisation and user involvement.

Instability in the client organisation

In several projects the client organisation was changed during the process. This caused considerable problems. In one project several key persons were exchanged at different points in time. The head of the client's real estate division was exchanged after the project had started. A professional construction management company was engaged. This company went bankrupt, and another company was engaged. In this company the project manager was exchanged after a few months. All these changes delayed the project. To accelerate the project process, the client therefore decided to divide the project in fifteen separate contracts instead of one. After the design was finished, the user organisation was formed. For instance, the key person became employed during the production phase.

Project organisations lose knowledge when key persons leave the organisation. The project processes were stopped while the new persons learned the project and the established trains of thoughts. The division of responsibility became unclear and earlier decisions were changed.

> "We explained that this change in the client's basic organisation in no way will lead to a situation where the organisation comes in and tells us that we must do so and so…. 'Of course, we will not do that!' Their answer was crystal clear. 'The project is to be performed in accordance with the conditions set down in the finished drawings'…. Then you come to a reality in which you have a head (of the client organisation) who says, 'OK, I respect the things made, but I will change some things anyway. Why not do it now? It will be much cheaper to do it now than to do it later on." (Clients project manager, a consultant)

User involvement

Another cause of the lack of ability to make decisions was that the users were given great possibilities to give their points of view on the facilities very late during production. In a school project, the teachers were employed during the production phase. In a refurbishing of a shopping centre, contracts were written with several shop owners during production. In two other projects 10 and 30 user groups respectively took part in designing the building during production.

Composition of the design team

The importance of how to compose teams was obvious. In most projects the design was made by groups, whose individuals already knew each other. It simplified the co-ordination as well as the co-operation considerably. In project teams without earlier relations, the co-operation was considerably worse. In some projects only one or two designers were new in the team. The co-operation went well due to the fact that their roles were very well established except for the communication with the new team member.

> "You must be able to co-operate when you build, but it's even more important that you know each other, that you trust each other when designing because it's a job dealing with abstract components."
> (Architect)

> "The co-operation between us (the designers) has worked out well. We have worked together several times before, We know each other quite well. It has quite a large importance. It's easier to contact people you already know. You don't need to worry that they think you want to discuss trifles." (Structural engineer)

Composition of the production team

The importance of composing teams was of great importance also in production. In most projects, except the contractors' own workforce, unemployed workers were engaged[1]. The new workforce was proficient and motivated, but the people had not worked together before. In the projects where the teams knew each other, the co-operation worked considerably better.

> "…There were people on site who didn't know each other and who never had been working together. They came from different companies with different cultures. I believe this is a disadvantage. It's easier when you know each other and have worked together. Then you get the division of roles automatically and you know what it means to do what you should do." (Assistant project manager)

> "To have been working together before has enormous importance because then we know how we work and how we suit each other…. It may vary a lot how people work, and you are different people." (Foreman)

Involvement of the interior designer

The role of interior designer was found to be indistinct for the decision-makers. In several projects it implied that he/she joined the design team very late and therefore the co-ordination was disturbed. Already decided solutions had to be modified.

> "…I prayed and pleaded that they should hire an interior designer…. that they at least should do a program for the interior design. But the project management ignored it…. I believe that they don't understand. They considered it as an office building, in which you put pieces of furniture. They didn't realise that there are so many fixtures in this type of building (a university including laboratory)." (Architect)

> "…People believe that the interior designer will just come and hang up some curtains and put in some chairs and tables. But interior design includes so much more and it's important that we come in as early as possible in the design work. It has to do with the possibilities to arrange pieces of furniture in a room and where the doors are and all such things…" (Interior designer)

[1] In Sweden the contractor normally employs some groups of workers for a long period of time. However, during the recession lots of workers became unemployed. As a labour-market measure the government decided that, in all public projects, the contractor has to employ a certain number of unemployed workers.

Support to the site organisation

The contractor's support to the site is important. However, the site organisation often found this support insufficient. This was especially clear concerning the companies' improvement programmes. These programmes included for instance shortened production time and increased participation of the workers. Both examples were meant to be means to increase efficiency, instead they were understood as goals. One reason was that the programmes were implemented top-down. Responsibility was delegated, but the support was insufficient. The site organisations were interested, but they could not manage all new activities. The workers were introduced late in the programs and many had difficulties in finding their new roles.

> "They have ordered us to make these changes. For us it means more work. But we haven't got any support to manage it…" (Site Manager)

> "All of us (workers) are so unused to it…. You are so tightly linked to the production. There must be someone (a site manager) who serves you with materials and so on all the time.… You can often hear people say 'why must we sit here for several hours when we could have been out working'?" (Worker)

Support to the workers

The workers often lacked support from their site management. This was especially clear concerning the sub-contractors. Their managers often left their workers alone on the site, not giving them sufficient information.

Site managers, who took care of their workers, met them eye-to-eye every day and gave firm and clear instructions were most appreciated. However, it seems that some minor measures can also influence the motivation.

> "We lack some encouragement…. It's often enough that they think we have done a good job and they buy us a bun…. So you just get the tiniest appreciation…" (Worker)

A cake or a bun is seen as a symbol of appreciation.

6 Discussion and conclusions

The aim of this paper is to discuss causes of defects in construction. The discussion is based on an extensive mapping of defects. A complex set of causes lies behind the occurrence of defects. When this study was done there was a recession in Sweden. The construction industry, especially house building, was extremely slow. Several clients had financial problems and were forced to cut costs hard. Designers and contractors needed projects to survive and were forced to accept projects at low prices. In the hard competition the client also had the possibility to demand short construction time. Cost pressure as well as time pressure characterised many projects.

However, it is always individuals who act, and consequently it is always individuals who act wrongly. Most defects occur because of lack of motivation, especially forgetfulness and carelessness. Other causes are lack of information or

knowledge required for the specific task. There are many reasons for this. Individuals' actions are influenced by how the organisation is designed. Many causes can therefore be found in organisational aspects.

Uncertainty in the project organisation is a root cause of many of the defects that occurred. Unstable organisations create such uncertainty. Four types of organisational instability could be identified.

1) Gaps in vertical relationships. Two types of lack of communication were found between customer and supplier in the project organisation. First, there were often unknown customer-supplier relations, which means that the customer and the supplier never had met before. Such relationships lack informal routines for communication. Second, the suppliers' support to the customers was often lacking. Such gaps were obvious between the client and the designers and contractors, between the contractors' management at the main office and the site, and between the site managers and the workmanship. These gaps influenced the motivation.

2) Gaps in horizontal relationships. Lack of communication was also found between people in the same team. This was obvious in the design teams as well as in the production teams. Teams were composed of people and organisations, which had never met before. Such teams lack informal routines for communication.

The third and fourth types of organisational instability cause gaps in horizontal relationships.

3) The organisation is not created in time. Some key actors joined the organisation late. The real users were often unknown until the late stages of the process. The interior designer often joined the design team late in the design process. Both groups' roles were underestimated. The project organisation needed both groups' knowledge in earlier phases. Decisions already made had to be changed, and construction work had to be changed.

4) The organisation is changed. Key persons surprisingly often left the project organisation during the process. This was especially obvious for the client organisation. Knowledge necessarily gets lost. This type of organisational instability could also be seen when the project organisation carried out several projects in sequence. When one actor was exchanged to next project, communication problems arose.

Unstable organisations make the process more complex to control. More defects occur, which takes time to correct. Organisational instability was created because unknown suppliers offered the lowest prise, people often had to be picked from different places, companies went bankrupt and had to be replaced by other companies etc.

All four types of organisational instability have to do with how the project organisation is structured. The project manager and the parent companies' managers are responsible for structuring the project organisation. Therefore, it is a task for all managers to strive for stable project organisations as a means to reduce defects and defect costs.

7 References

Atkinson, A. (1998) Human error in the management of building projects, *Construction Management and Economics*, Volume 16, May, pp 339-349.

Augustsson, R., Hammarlund, Y, Jacobsson, S. and Josephson, P.-E. (1989) *Kvalitet i byggandet – kvalitetsfelkostnader* (Quality in Building Construction – Quality Failure Costs, in Swedish), Report 21, Department of Building Economics and Construction Management, Chalmers University of Technology, Gothenburg.

Bonshor, R.B. and Harrison, H.W. (1982) *Quality in traditional housing, Vol 1: an Investigation into faults and their avoidance*, Department of the Environment, Building Research Establishment, London.

Brunsson, N. (1985) *The Irrational Organisation*, John Wiley & Sons, Chichester.

CIB (1993) *Building Pathology - A State-of-the-Art Report*, CIB Report, Publication 155.

Dew, J.R. (1991) In Search of the Root Cause, *Quality Progress*, March 1991.

Gryna, F.M., (1988) Quality Improvement, in Juran, J.M., and Gryna, F.M. (editors), *Juran's Quality Control Handbook*, 4th edition, McGraw-Hill.

Hammarlund, Y., Jacobsson, S., and Josephson, P.-E. (1990) Quality Failure Costs in Building Construction, Proceedings, CIB International Symposium at the University of Technology, Sydney, 14-21 March.

Josephson, P.-E., (1990) *Kvalitet i byggandet – en diskussion om kostnader för interna kvalitetsfel*, (Quality in Building Construction – a discussion on costs of internal quality failures (in Swedish), Report 25, Department of Building Economics and Construction Management, Chalmers University of Technology, Gothenburg.

Josephson, P.-E., (1994) *Orsaker till fel i byggandet - en studie om felorsaker, felkonsekvenser, samt hinder för inlärning i byggprojekt*, (Causes of defects in building – A study of causes and consequences of defects, and impediments of learning in building projects, in Swedish), Dissertation, Report 40, Department of Building Economics and Construction Management, Chalmers University of Technology, Gothenburg.

Josephson, P.-E., (1998) *Defects and Defect Costs in Construction- a study of seven building projects in Sweden*, Working Paper, Department of Management of Constrfuction and Facilities, Chalmers University of Technology.

Leavitt, H. J. (1978) *Managerial Psychology*, Fourth Edition, The University of Chicago Press, Chicago.

Matousek, M., (1985) A System for a Detailed Analysis of Structural Failures, in Yao, J.T.P., Corotis, R., Brown C.B., and Moses F., (ed.), Structural Safety Studies, Proceedings, *3rd International Conference on Structural Safety and Reliability*, American Society of Civil Engineers, Denver, Colorado.

NEDO (1987) *Achieving Quality on Building Sites*, National Economic Development Office, Building Economic Development Committee, London.

Nowak, A.S. (1992) Human Errors in Structures, *Offshore Mechanics and Arctic Engineer, 11th international conference*, Vol. II, pp 335-341, Calgary, Canada, June 1992.

Söderberg, S. (1979) *Psykologi och arbetsorganisation* (in Swedish), Liber Läromedel, Malmö.

Wilson, P.F., Dell L.D. and Anderson, G.F. (1993) *Root Cause Analysis: A Tool for Total Quality Management*, ASQC Quality Press, ASQC, Milwaukee, Wisconsin, USA.