THE ROLE OF EARLY DETECTION OF HUMAN ERRORS IN BUILDING PROJECTS

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ABSTRACT

This paper discusses the possibilities for detecting human errors in building projects earlier than they are detected today. It argues that well-planned inspections can significantly reduce poor-quality costs. Errors can be seen as chains of events, including causes, human error, defect, consequences and corrective measures. Most such chains include repeated loops, which means that several human errors and defects occur before detection. A preliminary analysis of 2879 human errors is presented in the paper. Three cases of human error are discussed in greater depth. The effects on the cost are also discussed.

KEYWORDS

Error; early detection; human error; inspection; poor-quality costs

INTRODUCTION

Poor-quality cost is often stated to represent 10-30% of a company's turnover (Harrington, 1987, Gryna, 1988, Sörqvist, 1998). The same figures are often mentioned for building projects. However, real measures give lower figures. Research projects have shown variations from 0-12% of the total cost in building or civil engineering projects (Burati et. al., 1992, Josephson and Hammarlund, 1999, Nylén, 1999, Love et. al., 1999). The variations depend on the definitions and methods used (Gluch and Josephson, 1999). Most of these measurable costs can be associated with specific defects in products or interruptions in processes, and they are caused by human errors. Thus there is a good opportunity and an important task for companies involved in building projects to reduce these costs.

There are three principal strategies to reduce the costs of human errors (Josephson, 1994). *The first strategy* is to avoid errors. TQM-related research often deals with this strategy.

It is well known that many errors happen over and over again in building projects. *The second strategy* is to avoid repetition of old errors by learning from them. Research related to individual and organisational learning and feedback deals with this strategy.

This paper deals with *the third strategy*, which is to reduce the consequences of errors by early detection and correction. The paper is motivated by several reasons. Earlier studies indicate that many errors consist of several actions occurring one after the other before detection. The consequences of errors become greater and more and more expensive to correct the longer it takes to detect them. Earlier studies also indicate that many errors could quite easily have been detected earlier (Josephson and Hammarlund, 1994). Past research has focused mainly on the first and second strategies. The evolution of quality management is often described as a gradual shift from inspection to prevention. However, we believe that there is still much to be learned about early error detection in building projects.

Errors lead to defects, i.e., to deviations from what is intended. The purpose of this paper is to analyse the role of early error detection in building projects and to look at how early detection would influence error cost. Our research questions are:

- How many errors can be detected earlier?
- How much can error cost be reduced by earlier error detection?
- Which errors are most important to detect earlier?
- What do project organisations have to do to be able to detect errors earlier?

The study is based on data from a study made on building projects in the mid-90's. Error costs include actual costs for corrective measures. Future costs are not included. The study is limited to human errors detected on building sites during the production process.

We argue that there are very good possibilities for detecting human errors earlier. We also argue that all members of the project organisation should be responsible for addressing things they observe and consider out of the ordinary.

HUMAN ERRORS – CHAINS OF EVENTS

Josephson (1994) developed an error model based on theories of organisational learning, for example Argyris and Schön (1978), and based on the analysis of more than 2000 documented errors from building and civil engineering projects. The purpose was to understand how errors occurred and to reduce the consequences. Davis (1987), Porteous (1989) and CIB (1993) have developed similar models.

There is an obvious relationship between causes and consequences in error analysis. Matousek (1985) and Nowak and Carr (1985) describe this relationship by describing the error as a chain of events following one after the other. These chains include causes, human error, defect, consequences and corrective measures. They also, more or less, include single-loop learning or double-loop learning. The causes are often complicated and are difficult to find and to fully understand. Here we define cause in accordance with Gryna (1988) as a proven reason for the existence of an error. There are often several causes for the same erroneous action. There may be either combined causes, or a chain of causes. The term "root cause" is therefore sometimes used to describe the most basic reason for an undesirable condition. If the root cause is eliminated or corrected, the recurrence of the defect will be prevented (Dew, 1991, Wilson et. al., 1993). The causes and the root cause may exist at the individual, organisational and/or global level.

Every human error is closely related to a manifested defect. Here, "defect" refers to both defects in products and interruptions in processes. One defect may have one or several consequences, which lead to the necessity of one or several different corrective measures. The earlier a human error is detected, the fewer consequences will occur and the easier and less costly it will be to correct the deviations from what is intended.

Members in an organisation react when a human error or a defect is detected. Most often this leads only to revisions of the workflow. The organisation consequently preserves its mental models unmodified. Argyris and Schön (1978) call this type of learning "single-loop learning". In some situations, errors are detected which require the organisation to modify its shared mental models. This Argyris and Schön call "double-loop learning". Argyris and Schön point out that the distinction between these types of learning is not so definite. Single-loop learning is most appropriate for routine work and for increasing effectivity in organisational routines. Double-loop learning is more relevant for complex, non-programmable activities (Argyris, 1993). Argyris and Schön claim that most organisations do well with single-loop learning but have great difficulty with double-loop learning.

Sasou and Reason (1999) describe how the error-recovery process may fall into any of three stages: detection, indication and correction. This paper focuses on the first stage, detection of the occurrence. Once detected, recovery from an error will depend upon whether team members bring it to the attention of the remainder, the second stage. An error that is detected but not indicated will not necessarily be recovered, and the actions based on those errors are likely not to be executed. The last stage is the actual correction of errors. Even if the remainder of the team notices and indicates the errors, the people who made the errors may not change their minds and may not correct the errors.

Sasou and Reason have studied errors that occurred in the nuclear power, aviation and shipping industries. They found that failure to detect errors is influenced by deficiencies in communication, resource/task management, excessive authority gradient and excessive belief. Failure to indicate/correct is influenced by excessive professional courtesy and deficiency in resource/task management.

An example of a human error

Figure 1 describes an example of a human error and the chain of events. The example describes a metal section including a door, which had to be exchanged. The human error arose from a person who did not recognise the users' needs, which led to the wrong doors being ordered. In this case several actions followed the error before its detection, which seems to be typical for the most expensive errors.

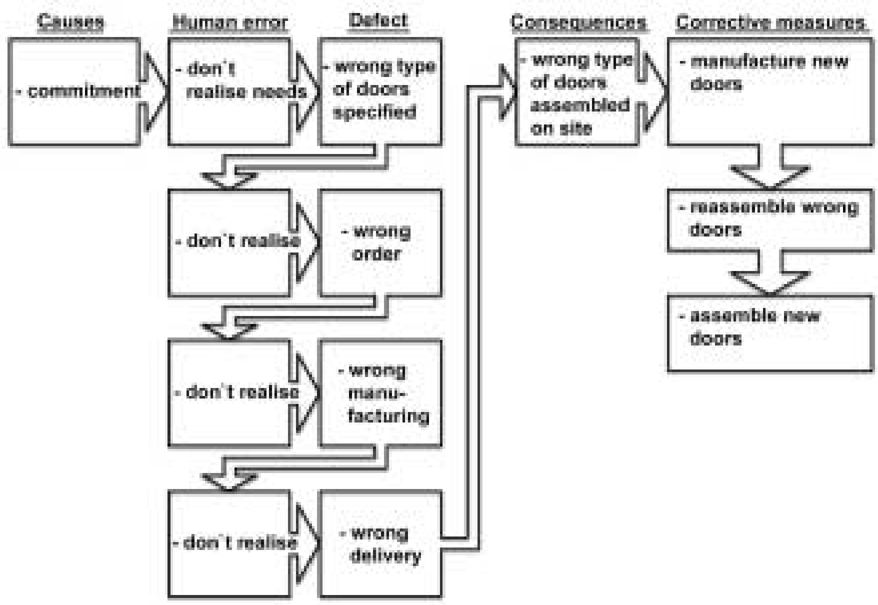

Figure 1: Several successive actions before detection.
(A metal section including a door had to be exchanged).

THE FIELD SURVEY

Seven medium-sized building projects, including both new construction and refurbishment, were monitored during a 4–6 month period in 1994-96. The aim was to register all errors occurring during the observation period. One observer was placed at each site with the single task of documenting errors. By making site rounds, the observers were in daily contact with all personnel. When necessary, they communicated with the client, designers, material manufacturers and other external sources of project information. Observers took part in meetings and read project documentation.

Each error was recorded with a special form. The first part of the form included codes and short descriptions of type of defect, activity, part of the building, actor, human cause, real time and cost of correction. The second part included full descriptions in text. Drawings, sketches and other relevant documents were attached to individual error descriptions. For each error, the possibility of earlier detection was judged.

The number of errors registered was 2879. The total correction cost was estimated at $750 000 (US dollars), which corresponded to 4.4% of the cost of production for the seven projects during the observation period. Across projects, the correction cost varied between 2.3% and 9.4%. The defect cost seems in many cases to be underestimated. Practitioners and designers as well as construction managers and craftsmen often commented on how low the estimation of the correction costs were. One conclusion, therefore, is that the costs are often underestimated and that early detection may have a more important influence on the cost than what is shown here.

Approximately 25% of the error cost were traced to faulty design, and 25% was traced to insufficient production management. Production management includes contractors (including sub-contractors), project management and site management. Twenty percent of the error cost originated in faulty workmanship and 20% originated in deficiencies in materials delivery. Smaller shares of the cost originated with the client or construction equipment.

The observers estimated that roughly 60-90% of all human errors was detected and indicated, 21% of the indicated errors were not fully corrected and 4% were not corrected at all. In this paper, the focus is on indicated human errors.

THE POSSIBILITY FOR DETECTING HUMAN ERRORS EARLIER

There is great potential for detecting errors earlier if knowledge from research projects in the field is used. In the survey mentioned above, the following findings strengthen this statement.

- More than 2/3 (72%) of the almost 3000 errors could, by judgement, have been detected earlier; 37% of the errors could relatively easily have been detected earlier and 35% could possibly have been detected earlier (Table 1).
- The errors that could be traced back to the client were often complicated and for that reason were more difficult to detect earlier. Almost 50% of the client errors were not possible to detect earlier.
- Design errors were surprisingly easy to detect in early stages. The practitioners indicated that most design errors could have been detected through separate examination of the drawings or by comparing drawings made by designers or contractors. More than 90% of all design errors were judged to be possible to detect earlier.
- 80% of the production management errors could have been detected earlier. Many of these were concerned with planning and work preparation.
- Workmanship errors could not have been detected earlier in as many cases as design errors and production management errors. The reason is probably that they occur late in the process. Only 60% of the workmanship errors could have been detected in earlier stages.
- Errors traced back to the sub-contractors include both management errors and workmanship errors. Almost 80% of these errors could have been detected earlier.
- 60% of the errors in material deliveries could have been detected earlier. Most of these errors were due to the manufacturing process in the factories.
- 50% of the machine errors could possibly have been detected earlier. Many of these had to do with a lack of maintenance. For that reason, problems with individual machines were judged to be more difficult to detect.

Table 1: The possibility of detecting different types of human errors earlier.

	Could the error have been detected earlier?			
	Yes, relatively easy	*Possible*	*No, not at all*	*Total*
Client errors	34	24	42	100%
Design errors	44	47	8	100%
Production management errors	40	38	21	100%
Workmanship errors	30	29	40	100%
Sub-contractor errors	46	33	22	100%
Material delivery errors	30	32	38	100%
Machine delivery errors	5	44	51	100%
All errors	37	35	28	100%

A natural conclusion is that the earlier in the process the sources of error are found, the easier and more profitable it is. This is logical because there are so many events in the error chain. Client errors and machine errors are exceptions to this rule, but only a few errors of these types were found in the study. That means that companies should focus primarily on early detection of design errors and secondarily on detecting production management errors.

THREE CASES

Method

Three typical errors - of the almost 3000 errors in the original study - representing different stages of the building process were chosen for a group discussion during the autumn of 2000. One architect, one structural designer, two contractors and the two authors took part in the discussion. The professional actors have 15-30 years of work experience. Three of them were involved in the original study. For each error, three questions were discussed:

- When should the error have been detected and indicated?
- How should the error have been detected?
- What would the correction cost have been if the error had been detected early?

Case 1: Smoking-room changed to non-smoking room

The first case considers a late change where user demands were not taken into consideration early enough in the planning process.

An old industrial building was going to be rebuilt and converted to a school. When most of the work was done, the users who were going to move in discovered that there was a room for smokers, which they did not think was necessary. They instead wanted to have a common room for all the personnel. The client – the local school authority – decided to follow the expressed wishes and some glass partitioning walls and some doors were dismantled and replaced according to the new plans. The cost for this late change was estimated at about $2550.

There are three main events in the error chain. (1) The client makes the program for the new school, without considering the user needs. (2) The architect makes a final program and layout with wrong input. (3) The general contractor constructs the school with wrong input.

The user arrives late to the new school project and detects the unwanted smoking-room. The room is then rebuilt into a non-smoking room. The central question is how soon demands from future users can be regarded in the building process. Three alternatives are possible. (1) The client is familiar with the user demands and he knows the operations well. He can therefore be seen as the user. This is, however, very unlikely in Sweden and it obviously did not happen in this case. (2) The architect has a lot of experience from similar projects and therefore knows the user demands. This may be so, but the problem is that he seldom has totally similar user groups and demands will shift from time to time. The architect's professionalism ought, however, to force him to learn the demands from the user in one way or another and to convince the client that this is very important for the success of the project. (3) The best alternative - if it is possible to implement - is to involve the user very early in the process. A group of users representing different functions of the organisation, together with an architect, should be able to decide which functions are necessary in the new building. It was not done in this project.

This case represents a common situation in building projects. People with the necessary knowledge join the project organisation too late. The group judged that the lack of need for the smoking-room should have been detected by the client during a discussion with a group of users after the first step above. In that case, the error cost would have been approximately $200.

Case 2: Beam in the middle of a room

The second error was also detected late. It considers the co-operation between the architect and the structural engineer in a new office building.

Late in the production process a site manager realised that a structural beam was assembled in the middle of an office room in such a way that it highly influenced the usability of the room. The beam belonged to the wind supporting structure on the top floor of the building. The architect had to redesign the room layout and hide the beam in a partitioning wall. Some of the walls had to be dismantled and new walls were built. The cost for correction was $950, excluding the lost value of the rooms. This error could have been detected and indicated by many different professionals much earlier than it was actually indicated.

An interesting question is why nobody reacted to this obvious error. It is not clear where the error chain really starts, but four main events can be identified. (1) The error chain starts in the communication between the architect and the structural engineer. (a) The architect made the overall design. Probably, he did not realise that there might be a conflict with the structure somewhere in the top floor. For that reason he did not make the structural engineer aware of that co-ordination problem. (b) The structural engineer designed the structure. The wind beam is one of the structural elements. The structural engineer did not take the partitioning walls into consideration. He did not do anything to facilitate the work for the architect either. It was probably quite easy to see on the drawings where the beams were crossing the space on the top floor. (2) The architect made the room layout for the top floor. At this moment he was not conscious of the supporting structure. (3) The general contractor built the structure. (4) A specialist contractor built the partitioning walls. It is curious that the craftsmen who did this work did not realise that the walls did not fit the supporting structure. Another question is why the site managers did not monitor what happened in this part of the building. A third question is why nobody else indicated the error. During that phase, lots of other professionals must have been on the top floor and must have seen the beam.
At last, a site manager did indicate the error and it could be corrected. The main question in this case is why nobody reacted earlier. Two answers are possible. Either they did not see or recognise the problem, or they thought that it was not their responsibility to react. Possible reasons for this could be that the drawings were not good and clear enough, the managers monitoring were not efficient enough or the incentives and motivation were inadequate.

The error should have been detected during the design phase, either by the architect or by the structural engineer. A specific occasion for scrutinising drawings would probably have been enough. A CAD overlay would have shown the problem to the architect at this stage. If this had happened, the error cost would have been less than $50. A second chance to detect the error came during the production phase. A better planned monitoring process would have helped the site manager to detect the error earlier. With better incentives for co-operation between the actors in the process, somebody might have reported what had happened.

Case 3: Missing holes in the wall
The third case considers an error made by a site manager during the production phase.

On the top floor of an industrial building several rooms for ventilation equipment machinery were to be built. The inner walls were of cast concrete. Lots of pipes and ducts were supposed to cross these walls. However, no holes were made in the concrete walls. For this reason, all holes had to be drilled afterwards for an extra cost of about $1200.

The error chain is described as follows: (1) The site manager prepares for the craftsmen so they can do their work. In this preparation he also orders material, arranges for scaffolding, allocates craftsmen to the tasks and informs the craftsmen of what they will do. All information must be taken from various drawings and descriptions. The error originates when the site manager failed to convey information from the HVAC-drawings to the craftsmen; he did not mark holes on the formwork drawings. (2) The construction workers made the formwork and reinforcement work without holes in spite of the fact that there would be pipes and ducts going through the walls. (3) HVAC-contractors did not observe the missing holes in spite of their presence on the site.

In this case the site manager made the error. He should have detected the error himself by a final check of the formwork drawings before handing them over to the craftsmen. If this had happened, the error cost would have ended up at less than $10. More and more project teams use CAD-systems for design etc. This makes it easier to detect such errors.

The construction workers got a second chance to detect and indicate the error. For some reason however, they did not indicate the error in this case.

ANALYSIS AND CONCLUSIONS

The most expensive errors often have several and complicated causes and it may therefore be difficult to fully avoid them. Instead, it could be important to concentrate on early detection. This paper concerns reducing costs of human errors in building projects and it focuses on one of three principal strategies - how to detect and indicate errors earlier. The paper presents preliminary results from an ongoing study.

The study indicates that almost 70% of all human errors in building projects can be detected much earlier than they are in fact. More than 35% of these defects could *very easily* have been detected earlier. All human errors can be seen as chains of events. Many of the most expensive errors have long chains and they consist of several repetitions of actions based on wrong prerequisites. The longer the chain is, the more costly the corrections are. The three cases analysed in the paper show that a large proportion of the error cost can be avoided by early detection. Further analysis indicates that more focused inspections may reduce the total error cost by more than half. It seems to be highly important to focus on detecting design errors and management errors as early as possible. One reason is that these types of errors are common, comprising 51% of the error costs. Another reason is that these types of errors are judged to be easier to detect earlier than other types are.

Many design errors concern co-ordination of information of drawings from different groups of designers. Most of these errors could have been detected if drawings had been examined and compared with each other. This is sometimes done systematically by contractors. CAD and other computerised systems will help to detect design errors early. Management errors are of different types, but most of them have to do with planning and work preparations. The site managers could detect many of these errors by walking around and following the work on site. The construction workers have an important role in early error detection. The workers made few errors themselves.

However, they could have detected many of the errors during their work on site. It is in this phase that the design and the management errors start to be expensive if they are not detected.

The three cases discussed in this paper show that the problem is not only the need to detect errors as early as possible. It seems that errors sometimes are detected but not indicated, i.e., reported to the people who are responsible for the specific work and who can start the correction process. The reasons for not indicating errors may be two: lack of understanding and lack of incentives:

Lack of information about the project and the end product may cause a lack of understanding of how a specific task fits within the total project. If managers and workers had been aware of the building design and the production methods, there probably and automatically would have been a good early warning system. To achieve this, the project manager could give all project members – client, user, designers, site managers and workers – a very easy way to look at the final view of the project. This can be done with an easy-to-reach model – a physical or a virtual model, a scale model on the building site or a virtual model on touch screens close to where people work.

Lack of incentives. People working in the construction industry are highly motivated. But there are still surprisingly many examples of errors that make one wonder why nobody reacted earlier. Why do people see errors and their consequences without telling anybody or doing anything to correct the errors? One reason may be the existing sub-optimisation in building projects. People and groups of people work hard and in a focused way to do their single task as well and as cost-effectively as possible without considering the total project.

This paper is a first report from an ongoing study. In the next step, the 288 (10%) most expensive errors in the original study will be analysed and discussed by the group of two designers and two contractors.

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