DIGITALIZATION OF INSPECTION DATA: A MEANS FOR ENHANCING LEARNING AND CONTINUOUS IMPROVEMENTS?

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According to Total Quality Management (TQM), Lean Production and Six Sigma literature, companies should develop organizational arrangements that foster learning from experience and base decisions on facts, since continuous improvements require continuous experience feedback in some form. In Sweden every construction project is checked in several inspections, and data about defects are collected in paper-based "punch lists", but what happens to these data after the defects have been corrected and the building is delivered to the client? This study describes the current inspection regime in terms of the scope it provides for collecting experience feedback in the Swedish construction industry, and evaluates the extent to which Swedish construction companies recognize this scope. Empirically, it is based on a survey of the views of field superintendents in medium-sized to large building/construction contractors regarding the use of inspection data as a source of experience feedback in their respective companies. The results show that contractors are generally aware that inspection data can provide valuable information for experience feedback and constant improvements, but currently they do not have systems or processes for feeding back experience from inspections. The possibility of replacing paper-based punch lists with a digital system to process and access inspection data is discussed, which it is proposed could provide a means for improving organizational experience feedback-based learning among construction contractors.

Keywords: automation, information technology, inspection, knowledge-based system, quality.

INTRODUCTION

The construction sector is generally considered to perform poorly in terms of learning and improvement. For example, according to Latham (1994) construction industry practitioners believe that approaches promoting the management of the corporate memory of their organization would help to overcome many of the constraints inherent to their sector. However, it has been found that feedback and learning loops are often broken in project-based organizations (Gann and Salter 2000) and that project-based companies lack organizational mechanisms for transferring and applying knowledge acquired from one project to other projects (Prencipe and Tell 2001, Dubois and Gadde 2002). Staff generally tend to ignore feedback processes, or

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have too little time to organize or facilitate feedback (Sterman 2000), and as project-based organizations become increasingly decentralized (Lindkvist 2004) and loosely coupled, effectively sharing knowledge becomes increasingly challenging (Orton and Weick 1990). The focus is generally on projects rather than processes, which is a key difference between construction and manufacturing industry cultures (Riley and Clare-Brown 2001).

The Swedish construction industry is regulated by two sets of General Conditions of Contract: AB 04 for (traditional) performance contracts and ABT 06 for design and construct contracts (BKK 2005, BKK 2007). These General Conditions have been drafted by representatives of both contractors and clients, hence they should be well balanced and provide a contractual framework that can be used to facilitate agreements that are acceptable for all parties involved in specific projects. Among other contractual matters, AB 04 and ABT 06 regulate the use and purpose of inspection.

A Final Inspection is compulsory, as well as a 2-year Guarantee Inspection. The client appoints a person he or she feels "is competent" for the job (BKK 2005), usually a consultant construction engineer specializing in inspection. Many of the inspectors are educated by the Swedish National Federation of Construction Engineers (SBR) and certified by SP SITAC (a subsidiary of the SP Technical Research Institute of Sweden) in cooperation with SBR, although there is no requirement for certification. After the inspection the inspector writes an inspection report including a defects list (punch list), which is sent to both the contractor and client. The contractor can then start to correct the defects. In AB 04 and ABT 06, the final inspection is seen merely as a compulsory point at which the project is accepted by the client and legally handed over from the contractor. The 2-year Guarantee Inspection checks for any new defects that may have surfaced since the final inspection (BKK 2005, BKK 2007).

Although regulations concerning quality inspection of construction projects differ between countries, similar problems are associated with current practice across countries, e.g. duplicated work, lack of standardization and poor communication between on-site contractors and tradesmen. In addition: data are generally manually collected on paper; there are difficulties in monitoring the correction of defects; systems for analysing and verifying causes of defects, and compiling statistics on defect rates etc., are poor or non-existent; and there is usually no feedback system. Cox *et al.* (2002) and Kim *et al.* (2008) focused on possible technical approaches to develop and implement an efficient feedback-incorporating inspection system. Such a system could be categorized as part of a Project Knowledge Management (PKM) system. Information technology (IT)-based support has proven to be a necessary, but not sufficient factor for high-quality PKM. Without good IT-tools PKM is difficult, but the tools themselves are not sufficient to ensure effective PKM if the corporate culture does not encourage their use (Hanisch *et al.* 2009).

The purpose of this paper is to investigate the extent to which construction companies today recognize that inspections can serve as valuable sources of experience data for continuous improvements, rather than simply as a compulsory step towards project handover, and whether they feel a need for an IT tool to support such use.

The following sections present the theoretical framework of the study. Then, the methodology and results of a survey of Swedish contractors' representatives' views of inspections and experience feedback are presented and discussed. Finally, conclusions regarding the implications of the results are drawn and issues that warrant further research are noted.

QUALITY IN CONSTRUCTION

Prompted by customer demands, government legislation and less formal governmental concern, quality management within the Swedish construction sector has intensified in recent years. Laws and regulations have been sharpened to emphasize the importance of quality control, for instance a “Quality Plan” concept was introduced in the Swedish General Conditions of Contract, 1994 (AB 94), and a Plan for Inspections was introduced in the regulations that came into force in 2004 (BKK 2005). Authorities in Sweden require construction companies to have certain knowledge of ISO 9001 (BFS 1996). However, the increasing demands from clients for quality assurance have led to companies implementing a top-down quality approach because their motivation for adopting quality management principles and routines springs solely from a desire not to lose customers (Dale 1999; Gustafsson *et al.* 2001; Poksinska 2006).

Total Quality Management (TQM) approaches can be summarized in five principles or core values; (1) focus on the customer, (2) base decisions on facts, (3) focus on processes, (4) improve continuously, and (5) foster commitment at all levels in all participants (Dale 1999). The cornerstones are supported by a set of techniques (including Six Sigma, QFD, QC circles, Benchmarking, Supplier partnership, Process management and Self-assessment) and tools (including Design matrices, Pareto diagrams, Quality house applications, Tree diagrams, Ishikawa diagrams, Process maps and Control charts (Bergman and Klefsjö 2003), many of which are also used in the Lean production system (Arnheiter and Maleyeff 2005). Low and Peh (1996) suggest a framework for implementing a Total Quality Management (TQM) quality system in construction. However, it has substantial impediments, summarized by Low and Teo (2004), who state that the success of TQM is yet to be proven in construction. Numerous barriers hinder efforts to improve quality, e.g. failure to: correctly understand customer requirements, both internal and external; understand the capability of the production system; track defects; improve sub-optimized processes; and track quality costs (Sower *et al.* 1999). A common feature of all of these obstacles is that they originate, ultimately, from poor management and deficient communication (Deming 1986; Svensk Byggtjänst 2007, Josephson and Hammarlund 1999).

The core objectives in Lean theory are waste elimination and value creation (Womack *et al.* 2007). Liker (2004) presented 14 management principles to help companies adopt Lean working methods, which could be categorized in four groups, the fourth being "Continuously solving root problems". This is to be implemented last and is a fundamental element of attempts to improve quality by minimizing defects and mistakes.. Essential aspects of this category are to: "go and see for yourself to better understand the situation", "make decisions slowly by consensus by thoroughly considering all options, then implementing them rapidly, and "become a learning organization through relentless reflection and continuous improvement" (Liker 2004). Continuous improvement is also important in Lean construction theory, e.g. one of Koskela’s (1992) 11 Lean principles for the construction industry is that companies should incorporate continuous improvement into their processes.

Experience feedback

The nature of experience lies in its practicality, i.e. something needs to be done to actually gain an experience. Therefore experiences, as well as knowledge, have both tacit and explicit components. The more explicit parts can be relatively easily documented and explained, but if the person who had the experience participates in the feedback process some of the more tacit elements may also be fed back.

Examples of experience feedback for continuous improvement include improvement of.

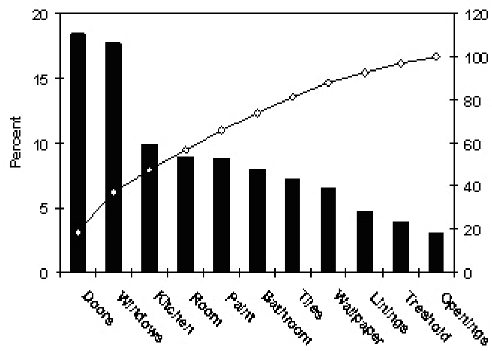
- Processes; when employees feed back their experiences in terms of how well the organization works regarding any aspects, from management strategies to specific work methods.
- Means; when employees feed back their experiences of how well equipment, machines, software, tools etc. work.
- People; when employees feed back their experiences of how well certain people work.
- Products; when employees working downstream of the construction design process, or customers, feed back their experiences of how well products are produced, maintained, used and so forth.

According to Juran (1986), any production is charged with a current level of chronic waste, which can be regarded as the level of opportunity for improvement. From a quality management perspective, defects are signs of sub-optimal product quality and must be detected in order not to reach the customer (Feigenbaum 1991). From a Lean perspective, defects are seen as one of seven types of waste in production, resulting in reductions in long-term profit (Liker 2004).

A recent defect study was conducted by Sigfrid (2007). The study was financed by the Swedish National Board of Housing, Building and Planning (implying that its recommendations may be generally applied). Calculations (based on housing production in 2005) presented in the study indicate that the costs of correcting defects after project delivery in Sweden could amount to 1 300 €M per year calculations based on the 2005 years housing production. The report states that defects are indications of organizational shortcomings and inadequacies in the construction industry.

Josephson and Saukkoriipi (2007) state that Defects, one of their Four Biggest Wastes, account, in various ways, for up to 10 % of the total project costs in construction; e.g. costs of hidden and visible defects and inspection costs. Other estimates suggest that costs of correcting defects may account for up to 6% of production costs, highlighting the importance of acquiring knowledge about both costs and causes of defects in order to prevent them arising (Josephson and Hammarlund 1999).

Johnsson and Meiling (2009) examine the severity of defects in industrialized house construction, and suggest that existing defect notations are a neglected source of quality improvement information, which can be used to help realize the benefits of off-site construction. In the cited study, information about defects is extracted and codified from quality documents, compiled during the construction and inspection processes, regarding 11 projects covering 2415 defects, representing ongoing types of waste as long as the companies concerned neglect to access and analyse the causes, and ways to address, the recorded defects (Figure 1). The main reasons for investigating defects are to reduce costs associated with poor quality and to improve production efficiency, product quality and customer satisfaction.



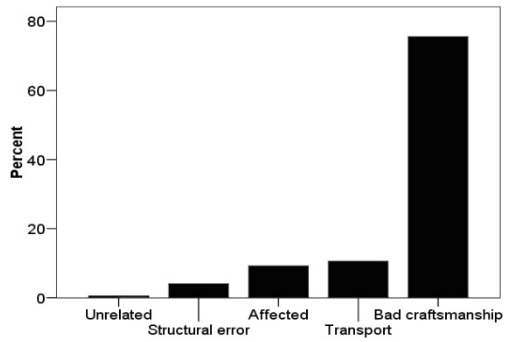


Figure 1: Summary of analysis of 2415 defects arising in 11 projects, from Johnsson and Meiling (2009).

METHOD

Survey design

The survey was set up through a common web survey service, using individual participant links to the survey. This facilitated the possibility to send out reminders to those who had not yet responded, and provided a certain level of confidence that company representatives selected for inclusion in the sample were the actual respondents. There was also a possibility for respondents to voluntarily enter contact data at the end of the survey, giving further proof that selected representatives were the actual respondents. Answers were anonymized before data analysis.

The survey consisted of several groups of questions concerning matters ranging from general quality strategies to more specific questions about inspections. The inspection-specific part of the questionnaire consisted of nine Likert-scaled statements and two open-ended questions. The answers from the open-ended questions were analysed and categorized/codified to enable conclusions to be drawn from the data.

Populations and sampling

In a first round, the survey was sent to 66 site/production managers and project/factory managers in both medium and large-sized construction contractor companies in Sweden, all of which were members of the Swedish Construction Federation. The companies were both traditional, mostly on-site producing contractors, and members of the industrialized segment, mostly off-site multi-storey housing producers; the authors indentified these as two separate populations. This first round was complemented with a second larger dispatch.

The two population groups were sampled in the same way, by selecting one or more site manager(s) and one or more project manager(s) from every company (more than two participants were selected for the bigger companies for reasons explained below). We wanted to maximize randomization of the sample, as much as possible, but overall the elements were sampled with a convenience approach. For some companies it was possible to obtain a random selection from a company-supplied list of all their available personnel in the population. However, for larger companies with subsidiaries operating in local markets in several regions, pairs of participants were selected for every region. One reason for this was to capture possible differences in ways of working between different parts of the country in the same companies, another was to obtain a better balance in the sample between the large and medium-sized companies. It was assumed that regionally organized divisions are of approximately the same size in every such company, but no attempt was made to check the validity of this assumption.

RESULTS AND DISCUSSION

Results show there was a response rate of 65 % (43 respondents), of whom 62 % (41) completed the survey.

41 (out of 43) respondents answered the questions about inspections. Out of these one respondent was female, 51 % (21) had a college education or higher, with 21 years experience of the industry, on average. 31 of the respondents were employed in a company working on a national market, five on a regional and five by smaller local companies. The respondents were employed in company types listed in Table 1.

Table 1. No. of respondents and the size of their company.

No. of respondents	Size	No. of employees	Annual turnover
3	Small	10-49	<10 €M
19	Medium	50-249	10-50 €M
16	Large	250-	>50 €M

25 (out of 41) respondents stated that most of their companies' production is conducted on-site. Nearly 60% (24 out of 41) stated that their companies were ISO 9000 certified, four were not certified, but were following ISO 9000 standards anyway, and 11 stated that their company had developed their own Quality System.

Responses to a question intended to rank the three most important sources of new knowledge and project-related experiences indicated that inspections were regarded as the least important source (Table 2). This is probably because there is no good way in today's practice to get knowledge out of inspection reports, and it is a strong indication that there is potential for future development in this area.

Table 2. Most important sources of knowledge and project-related experiences among the companies.

	Clients	Employees	Post-market	Sub-contractors	External sources*	Design consultants	Inspections
Percent	81	78	44	32	27	22	17
No. of responses	33	32	18	13	11	9	7

** Such as: University co-operation, monitoring of trends in the industry, trade fairs, external and internal training, in-company experts, experience meetings and cross-industry benchmarking.*

63% (of 41 respondents) stated that their company did not have a system for compiling defect data from inspections, but nevertheless 80 % agreed or fully agreed that their company had an expressed goal to reduce the number of defects in inspections (Figure 1). 46% agreed or fully agreed that their company actively analysed root causes of defects.

76% agreed or fully agreed that their company regarded inspection defects as valuable information, while as many as 88% personally agreed or fully agreed that reported defects from inspections provide valuable information. 80% of the respondents stated that their company has expressed goals to reduce defect rates. It seems that the respondents mostly agreed with the official company standpoint on inspection data and the common opinion was that useful information is hidden in the reports.

However, 51% of the respondents (21 out of 41) disagreed or fully disagreed that their company made use of these defect data in their improvement work – still 62% of these 21 stated that their company regarded the information as useful and 71% that their company has an expressed goal to reduce the number of defects in inspections.

These findings raise questions about the discrepancies. It is remarkable that half of the respondents felt that their company did not make any use of inspection data for improvement, although most of them regarded the information as useful, and up to 80% of the companies did even have expressed goals to reduce defect rates. A possible explanation is that the companies had not yet started, but were planning, to address these issues in the near future. These questions need further research, and are not further considered in this paper.

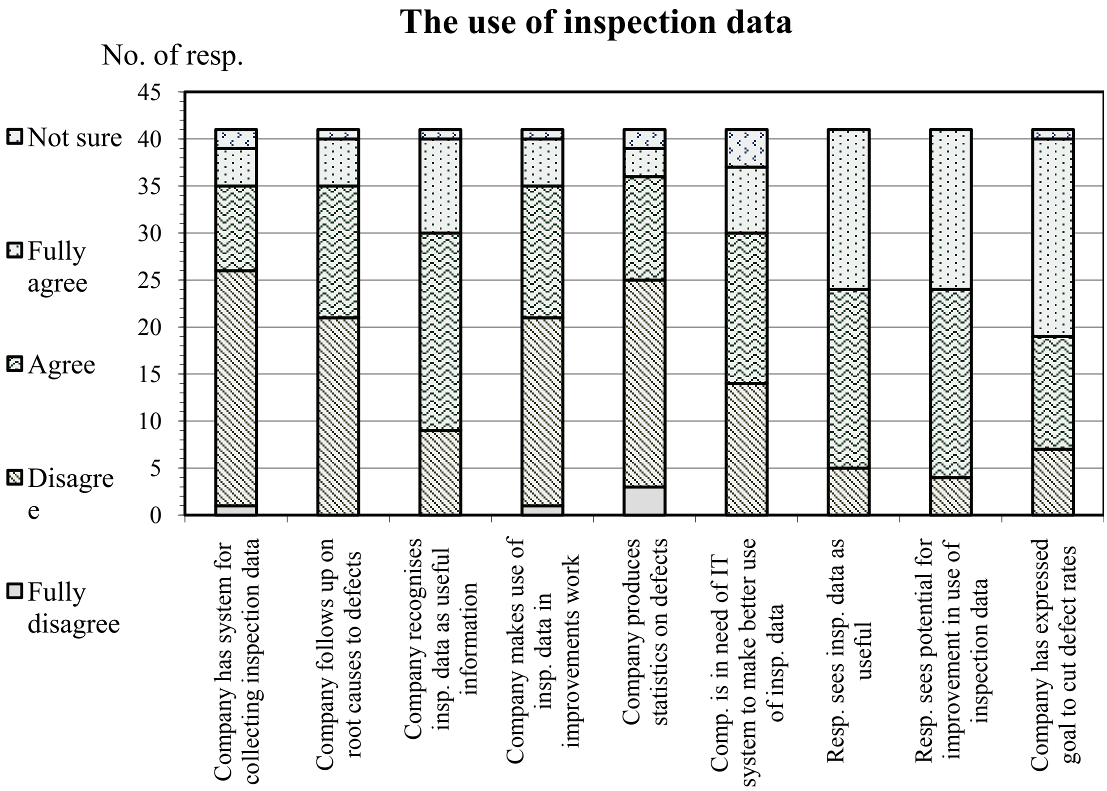


Figure 1: The use of inspection data

34% (14 of 41) stated that their company are compiling statistics about defects. As many as 90 % agreed or fully agreed that the use of defects data in their company could be further developed. In responses to a question regarding whether or not they felt assured that defects from one project would not appear in future projects, 54% disagreed of fully disagreed. 56% (23 of 41) agreed or fully agreed that their company needed a supporting IT system to better manage information from inspections, while 34% did not agree.

It is not surprising that so few contractors are mining statistics from inspection data, since obtaining relevant information from current manually compiled, paper-based data sources is highly resource-demanding. Hence the results may reflect unease about the current situation, and awareness that something has to be done, combined with resistance to implementation of an appropriate IT system, due to the complications involved in incorporating such a system into an already broad, diverse and decentralized IT fauna.

26 (of 41) respondents chose to answer the open-ended questions about inspections, and the responses were categorized according to the stated accessibility of the inspection data (Table 3).The answers imply that many companies have started to store inspection reports, in formats such as project portals, a first step towards a more intelligent solution. Data stored in this way cannot be directly searched and the mining of statistics is still manual, but they are more accessible than on papers contained in a binder in some office.

Table 3: Codified results from open-ended questions on inspection data handling practices

In what way are defect data from different projects saved within the company?

	Paper-based archive (e.g. binders)	Digitally within projects (e.g. in digital reports on project portals)	Digitally between the projecs
No. of comments	12	12	2

Lower level of accessibility ⟷ Higher level of accessibility

In what way is information from inspection reports used within the company?

	No use at present	Ad hoc - no formalised routines for feedback or documentation	Through formalised routines for feedback
No. of comments	7	12	7

The responses to the second inspection question, concerning the way in which companies use information about defects, show that most companies try, in some way, to note the most common defects and to solve the root causes, but without formalized routines.

On defects

Since defects data are already available in mandatory inspection reports these sources represent a low-hanging fruit, raising questions about why the companies currently use inspection reports only as checklists for correcting defects and make little use of information captured in the audits for further analysis. We believe this is due to several reasons. Firstly, there are no explicit demands to do so from clients or authorities. Secondly, there are cultural reasons (based on norms of traditional on-site and project-based construction); if the development of product quality in the housing industry is to be conducted through the organizations concerned, the poor use of defect data indicate a need for learning rather than a technical, economic problem. The most alarming effect of defects is not the cost of correcting them, but the associated reduction in product quality. The two main reasons for investigating defects are to reduce poor quality costs and to improve product quality and customer satisfaction.

On sampling

In the survey design process it was initially decided on a probability sampling approach in that the authors should randomly select the participants for the samples from company provided lists of their total record of site/production and project managers, a sort of stratified sampling. That approach proved to be very difficult follow. Many of the smaller companies had only a few persons on the requested positions, i.e. not much to randomize. Other companies were not eager to hand out lists of their employees, claiming privacy reasons, and the choice would then be between not asking the company at all to accept those few names provided. Thus it presented a non-probability convenience sampling approach.

Among the two population groups in the survey, the traditional mostly on-site contractors and the industrialized, mostly off-site housing produces, the latter is the smaller number in the matter of share of the building market.

CONCLUSIONS

This paper investigates to what extent construction companies currently recognize inspections as more than a compulsory step towards project handover, but also as a good source of experience data for continuous improvements. Contractors need to make continuous improvements, and it is suggested that many improvements could be facilitated by knowledge about common defects. Contract (final and guarantee) inspections are already mandatory activities in the Swedish construction industry, and conducted on a regular basis, but the information they provide are generally used solely to correct defects before handover to the client. As Johnsson and Meiling (2009) showed, statistics can already be drawn from the current paper-stored data, but the current practice is too resource-consuming and difficult for this to be really powerful and more widely applied.

The empirical data gathered in this study suggest that there is a strong feeling among the contractors in general that inspection data provide valuable information, and some also try to use it for experience feedback and constant improvements, but most companies lack a system or process that supports the feedback of experience-based information provided by inspections.

Future research

It is clearly in the interest of the contractor to develop and implement experience feedback systems that support the input of inspection data for continuous improvements, but this requires the inspectors to conform to the implemented systems, i.e. defect data must be delivered in an appropriate format. This possible obstacle and other uncertainties have to be investigated in future studies.

This study is the first part of a new PhD research project being conducted at the Luleå University of Technology. Next, an interview study with the different role types of construction projects will be conducted; aiming to answer what type of information they would like to pull out from a suggested digital inspection solution.

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