Simulation Experiment: The Effects of Experience & Interruption in Predicting Error Rate for a Construction Inspection Task

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Abstract: A significant number of performance failures in the construction industry can be traced back to human error in the construction phase of the project. The industry's most utilised method of ensuring a project's structural integrity (i.e. failure avoidance) is staged inspections throughout the construction process. Several factors influence the detection of errors during the inspection of a construction task. These factors include experience and skill of the inspector; communication; complexity; environment; size of the construction tasks; and interruption. Such factors can vary from one organisation to another and from project to project. The research outlined herein investigated the effect of experience, education and interruptions (delays) on the total inspection time and error detection rate (EDR) of inspectors for a reinforced concrete slab construction task. As may be expected the study found that as inspection time increased (with some deviation) so too did the detection of errors. The research also considered the relationships between inspection error and weather and inspector mood conditions at the time of inspection. The highest numbers of inspection errors were found to be in concrete reinforcing. The study showed that neither education nor experience alone produced an acceptable inspection result. Even inspectors with over ten years of experience in the construction industry were found to have a lack of satisfactory competence in several areas. This study found that the effects of learning and forgetting are evident in both experiential and direct educational training.

Key words: Construction Industry, Experience, Error Detection Rate, Inspection, Interruption and Simulation.

INTRODUCTION

The importance of determining optimum inspection policy for large construction projects cannot be underestimated. The advent of quality assurance and the increase in litigation has seen a change in the way building contractors and sub-contractors view quality. The traditional concern was often "Will the client be satisfied?" Now with a concern for reducing liability and being seen to meet standards the concern is often "Will the inspector be satisfied?"

In the commercial construction industry, a passed inspection takes legal liability from the sub-contactor and places it squarely on the shoulders of the main building contractor who employs the inspector. As such it is imperative that the inspector is capable of completing the task successfully in reasonable time and at reasonable cost.

Stewart [1992a] suggests that humans are the weakest link in the construction process, from design through completion. This is evident when qualified inspectors still fail to detect all errors within their range of influence. Kletz [1991] shows that 9 out of 10 serious structural accidents can be traced back to some form of human error, while Eldukair and Ayyub [1991] point out that 56% of these errors occur during the construction stage of the project. Even though not all inspection failures will produce disastrous effects, every failure indicates a lack in the level of quality that should and could be produced.

Atkinson [1998] points out that there has been a great deal of research into safety related human error in most industries, yet less research into the recognised area of human error that causes defects, reduced utility, premature aging, increased maintenance costs and the like. He goes on to note the causes of human error. For individuals he contemplates the psychology of error and draws on Reason [1990] who divides error into three parts, skill based error and lapses, rule based errors and knowledge based errors. Each of which is particularly relevant to the consideration of human error in inspectors.

Reason [1990] in Atkinson [1998] states that *errors are the acceptable and usually acceptable price human beings have to pay for their remarkable ability to cope with very difficult informational tasks quickly and...effectively.* This perspective covers genuine errors. However, he notes that errors are also often caused by deliberate deviations from accepted practice due to the natural human tendency to take the path of least effort.

Atkinson [1998] notes several sets of causes for errors, one of which is managerial causes. Within this he observes the major causes to be failures in communications, errors caused by concurrency, errors caused by changes, confusion of responsibility and most importantly in the study of inspection – failings in checking, supervision and control.

The research outlined in this paper is based on an experiment in which a number of inspectors of varying education levels and years of industry experience were asked to inspect a reinforced concrete slab with a number of inbuilt errors prior to pour. The experiment primarily considered time, inspector education and inspector experience. However, factors such as inspector mood and the weather/temperature were also considered and analysed for relationships.

THE EXPERIMENT

The experiment detailed below involved 41 inspections of the same 3m x 6m slab. The form and reinforcing steel was set up and ready for concrete pour to simulate a slab on a construction site awaiting the inspector's approval.

The Concrete Slab

The concrete slab shown in Figure 1 was specifically designed for this study. The slab included 4 edge beams (400 x 300) and two block outs (800 x 600 and 600 x 650). Whilst the experiment attempted to remain generally typical of what might be found on site it was necessary to over-design the slab to permit the inclusion of more defects.

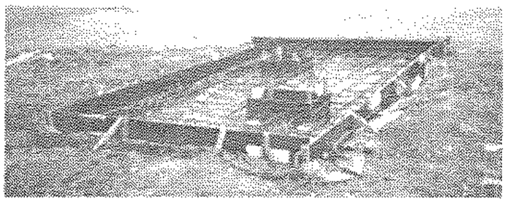

Figure 1. The completed Slab

The slab contained 32 intentional defects. 12 formwork defects, 16 reinforcement defects and 4 workmanship defects. The defects were as wide ranging in nature as possible, within the above constraints, to allow the inspectors the opportunity to show their ability at detecting various types of error.

Many of the intentional defects ranged amongst the following:

- Reduced number or size of reinforcing bars.
- Increased number or size of reinforcing bars.
- Decreased effective depth to tensile steel.
- Increased effective depth to tensile steel.
- Decreased overall depth of the concrete slab.
- Increased overall depth of the concrete slab.
- Decreased width.
- Increased width.

Stewart [1992b] has shown that these eight error types are responsible for the majority of failures in reinforced concrete poured in-situ.

The Inspection Process

Two inspection processes were carried out over a six-week period. Details about these inspection processes are outlined below.

Inspection Process 1

Forty-one inspectors in all inspected the slab for the purpose of the experiment. These inspectors ranged from first year graduates to professionals with over ten years of industry experience. Each inspector was provided with an identical checklist and equipment. All inspections were done in fine weather of varying temperature.

Each inspector was provided with approved plans, drafted to industry standard, for the concrete slab and then given an unlimited amount of time to inspect and report (checklists with comments) on defects.

Inspection Process 2

An inspector with limited construction industry experience was asked to repeatedly inspect the above slab with similar induced errors. The first five(5) inspections were completed consecutively within 1 week. Weekends were considered as an interruption. The inspector was then requested to inspect the same slab at three (3) to seven (7) consecutive days interval; to simulate the delays caused by equipment break down, inclement weather and industrial dispute, etc. This pattern of inspection was used to determine whether interruption/delays causes any decrease in error detection rate (EDR) or increase in inspection time.

Data

Data was collected and placed in spreadsheets indicating the following:

- Experience of the inspector (education/qualifications).
- Other knowledge
- Errors detected/Errors not detected.
- Total inspection time.
- Slab approval (inspection pass/fail)
- Mood of inspector.
- Weather conditions/temperature at time of inspection.

Regression Analysis

A regression curve was plotted to assist in drawing conclusions about the quantitative values. Regression analysis indicates the existence or otherwise of a relationship between two or more variables and the possible strength of that relationship. For example how a labourer's performance is affected by factors such as age, experience, time, trade, etc. Shares are apportioned in the performance measure of each of these factors. This in turn allows the prediction of performance of a new untried labourer based on the same factors.

Every regression curve has a R^2 value that represents the regression co-efficient. This is the probable relationship between the variables involved. The higher the R^2 value the greater the probability the relationship exists. For example: $R^2 = 0.95$ indicates a strong likelihood of relationship; $R^2 = 0.25$ indicates a weak likelihood of a relationship. (Berenson et. al. [1993]).

RESULTS AND ANALYSIS

Education and Experience

Figures 2 and 3 below take into account the errors detected versus the two types of knowledge of the inspectors – education and industry experience. While both R^2 values are high, construction experience has an R^2 value of almost 1 indicating the extremely close relationship between experience and error detection. Although the R^2 value for education is lower it still indicates a strong relationship, which in turn points out the necessity of inspector education.

When the two charts are compared against one another it is also notable that inspectors of "professional" standing (University education and 5 years and over industry experience) have a greater error detection rate than that of "non-professional" (University education but no relevant industry experience). This further points out the need for inspector education and also shows that construction experience does not by any means override education in terms of inspection competence.

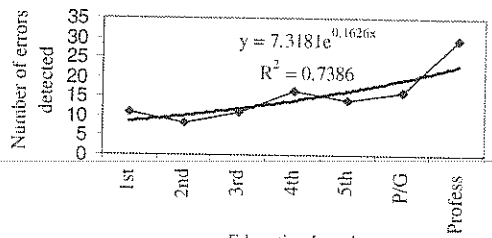

Figure 2. Education level vs. no. of errors detected

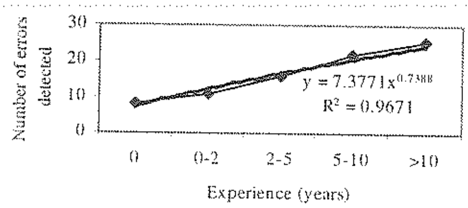

Figure 3. Construction experience (years) vs. no. of errors detected

Figure 2 shows an interesting trend of error detection decline between 4th and 5th year students and post-graduates before the steep incline heading towards professional status.

Initially this would appear to indicate that 4th year building students are better inspectors than their more educated counterparts in closely following years. Figure 3 shows a steady trend of increasing detection rate with industry experience. The immediate post-fourth year decline taken in context with

Figure 3 tends to indicate that with the relatively small sample size the fourth year students utilised in the experiment had greater industry experience than their aforementioned counterparts.

It is outside the scope of this paper to decide what a reasonable rate of accuracy is. In deciding the optimum rate of accuracy there are issues outside those discussed here that must be taken into account, not the least of them the cost of 100% accuracy. However, these results may be of use to that very research that could provide us with an indication of what is required to be a competent inspector. Considering the results of the study it can be seen that inspectors of professional standing can be deemed the most competent (29.5/32 errors – 92%). Inspectors with greater than ten years industry experience achieved what might be considered a slightly less adequate performance (25/32 errors – 78%).

Time and Experience
The R^2 value of construction experience vs. time is also approaching 1 as seen below in Figure 4.

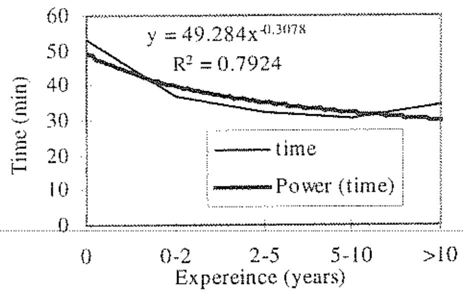

Figure 4. Construction experience (years) vs. time

There were two expectations for experience vs. time analysis. Firstly, the natural expectation that as years of industry experience increased, time taken to inspect would decrease due to task familiarity and improved efficiency. Secondly the less likely possibility that as experience increased time taken would marginally increase due to a greater detection of errors. As can be seen in Figure 4 the actual relationship proved to be more a combination of the two.

The expected decline in inspection time with experience initially took place. The inspectors with little or no experience took the longest time, possibly due to uncertainty and the time declined as experience increased through to 5 – 10 years experience at which point the time taken begins to increase once again. The reasoning for this can be better understood when considered in line with the number of errors detected as seen below in Figure 5.

Error Detection, Time and Experience
In relation to the upturn in time for ten years plus (seen in Figure 4), Figure 5 indicates that while not a strong relationship, the most likely explanation for this is indeed the initial expectation that with experience the number of errors detected increases taking extra time.

Primarily, it can be seen from Figure 5 that the relationship between time and error detection is limited. By finding the rate of error detection it was easier to establish a relationship. The 5 – 10 years group had an average detection rate of 0.71 errors per minute. The greater than 10 years group had an average detection rate of 0.73 errors per minute. Figure 5 does show clearly that there is a minimum amount of time to complete an inspection adequately, eg. around 32 minutes for a 50% error detection.

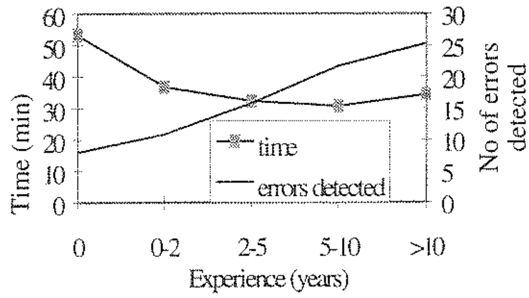

Figure 5. Construction experience vs. time/number of errors detected

Lessons in this are that while there is little relationship between error detection and time there is such a thing as completing the task too quickly to give it adequate attention.

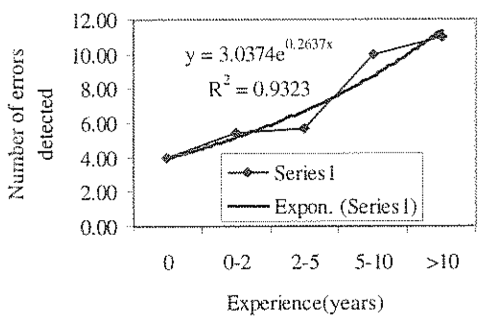

Figure 6. Number of formwork errors detected vs. construction experience (years)

Trade Errors
The 32 intentional errors ranged in difficulty from fairly obvious unstable formwork through to unobvious errors such as a short Y12 bar. The errors as previously mentioned were split into three trades – formwork, reinforcement and workmanship with the average detection

for each plotted against experience. Formwork errors detected vs. experience can be seen below.

The R^2 value for Figure 6 shows a strong relationship between experience and the ability to pick formwork errors. It can be seen that generally as experience increases so too does detection of errors. It is interesting to note the improvement rate against years of experience. Figure 6 shows that while over the first five years error detection only rose 1.66 (out of 12), in the following five year period, error detection rose 3.34, after which detection rose again by 2.3 for the over ten years experience group.

While no inspector found all twelve formwork errors, it can be seen that in this area inspectors with over 5 years experience have the most adequate understanding of what is required to competently inspect formwork.

There were a total of sixteen reinforcement errors in the slab, the graph of which, against experience can be seen below.

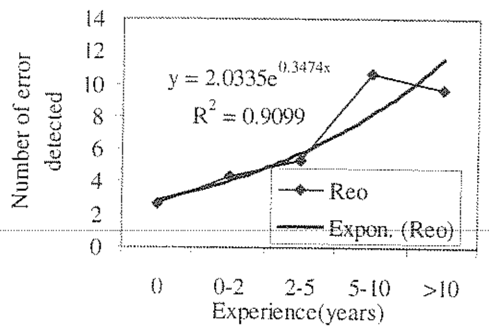

Figure 7. Number of reinforcement errors detected vs. experience.

A professional inspector with 5 – 10 years experience had the highest detection of errors in this trade. Figure 7 shows inspectors of 5 – 10 years experience being more capable of inspecting reinforcement than any other inspector experience range including those with more experience. The R curve with its steady increase in detection over time shows that this should not necessarily be the case. The R^2 value of 0.91 shows a reasonably strong relationship. As such it must be considered that either within the sample group there were an unnatural number of participant with a high level of reinforcement experience in this group. Or, the more likely solution that we are now beginning to see a higher level of education entering the inspection arena, meaning that more inspectors in this group are "professionally qualified" as opposed to a majority of "site-educated" inspectors currently in the ten years plus experience range.

Once again it may be seen from the R^2 value that there is a strong relationship between experience and the ability to detect workmanship errors. The increase in inspection competency is generally steady over experience and time. However, in deviation from the regression curve it can be seen that once again the 5 – 10 years group did better than might have been anticipated, probably for the same educational reasons stated previously.

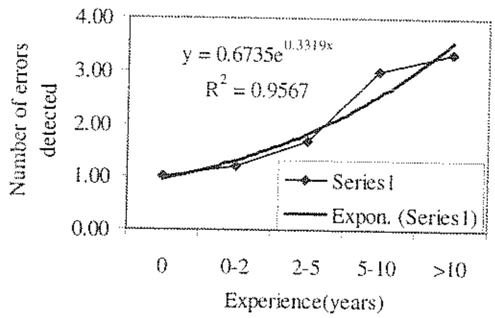

Figure 8. Number of workmanship errors detected vs. construction experience

It is noteworthy that even though the workmanship errors (including errors such as membrane not taped and unclean site) shown in Figure 8 should have been the easier errors to detect, only one inspector out of 41 detected them all.

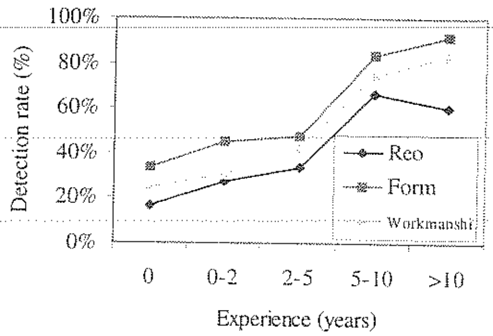

Figure 9. Error detection rate for different trade vs. inspector experience.

Figure 9 above sets out a graph showing the inspectors' varying error detection rates for the three trade areas in relation to the individual inspector's experience. As previously noted reinforcement had the lowest relationship (R^2 value) of the three to experience.

Figure 2 shows the highest detection rate being in the area of formwork and the lowest in reinforcement. While at varying detection rates, it is interesting that for the most part the three graphs travel parallel to each other up to 5 – 10 years experience. At this point formwork and workmanship continue in parallel and reinforcement takes a downward turn from its highest point of 67% back to 60% for the greater than 10 years experience range.

Reinforcement appears to be an area that particularly requires formal education to inspect competently, and probably more education than is currently involved as shown by the unacceptable highest detection rate of 67%. It is likely that as previously discussed the decline in the greater than ten year experience range is due to a lower level of formal education for those inspectors currently at this stage of industry experience.

Inspection Process 2 - Effects of Interruption
Results shown in Figure 10 suggests that there is evidence of a decrease in total inspection time and an increase in EDR (learning) due to repetitive inspections (the first five were uninterrupted inspections). Figure 10 also suggests that there is increase in inspection time and decrease in EDR (forgetting) in the second five interrupted inspections. The rate of improvement for the total inspection time is low and improvement in EDR is also poor because of this particular inspector's limited relevant experience.

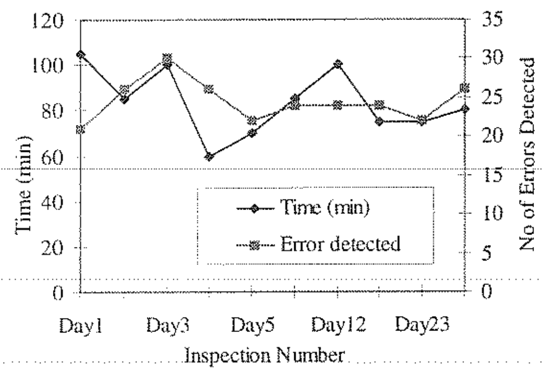

Figure 10. Effects of Interruption

CONCLUSIONS

While quality assurance systems push for an overriding care for quality throughout the construction process, at least for now, a great deal of the responsibility for quality and structural integrity within the project rests with the inspectors. Their ability and competence is an integral part of the overall, enduring success of any project.

It is outside the scope of this study to decide on the adequate level of competency. This study recommends that further research should be carried out to determine the optimum competency level for inspectors.

A survey by Ruben [1996] showed that in the USA, courses relating to construction failures lacked instructors with adequate training and experience. Herein lies the key.

It has been shown that neither education nor experience alone is suitable in producing a competent inspector. The effects of learning and forgetting are evident in both experiential and direct educational training. Only the inspectors with both experience and education, thereby taking them to a "professional" standing can truly be considered as competent.

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