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UNDERSTANDING INSPECTION CHALLENGES IN THE EPC INDUSTRY: A SIMULATION APPROACH

Thais da C. L. Alves[1], Kim L. Needy[2], Kenneth D. Walsh[3], and Deborah Chan[4]

ABSTRACT

How can the inspection task and its challenges be mimicked in a simulation? The purpose of the research was to use a simulation to highlight challenges and trade-offs faced by inspectors in the Engineering Procure Construct (EPC) industry. A literature review was conducted and results were shared and discussed with a group of subject matter experts (SMEs) who are part of Construction Industry Institute Research Team 308. A simulation was identified and modified to address important concepts related to the inspection process in the EPC industry. The simulation is more generic in nature to allow a broad-based audience to use it. Versions of the simulation were tested with students in a classroom setting and SMEs, their feedback was collected, and a final version of the simulation defined. Participants found the discussion about variables considered to be useful and the simulation to be a good representation of what happens in practice. Lean researchers often view inspection as a contributory or wasteful activity. However, inspection should be designed and managed like any other activity.

KEYWORDS

Inspection, Simulation, Nonconformances

INTRODUCTION

In the Lean literature, inspection is viewed as a wasteful activity that should be eliminated or reduced if processes delivering products and services are capable and reliable. However, the reality of the construction industry is that products are manufactured around the globe in environments that differ sharply from one company or country to another, and that might severely impact how products are delivered.

This paper addresses the challenges related to the inspection process through a simulation exercise that aims to abstract a product that needs to be inspected given certain

[1] Associate Professor, J. R. Filanc Construction Eng. and Mgmt. Program, Dept. of Civil, Constr., and Env. Eng., San Diego State University, San Diego, CA, USA, talves@mail.sdsu.edu

[2] Dean, Graduate School and International Education, University of Arkansas, Fayetteville, AR, USA, kneedy@uark.edu

[3] Dean, San Diego State University, Tblisi, Georgia, kwalsh@mail.sdsu.edu

[4] Undergraduate Student, UNICAMP, Campinas, SP, Brazil, dkchan_4@hotmail.com

constraints. The idea and the need to develop this simulation were born from discussions of the Construction Industry Institute (CII) Research Team 308 (RT308). The team had been investigating ways to assure products delivered to the Engineering Procure and Construct (EPC) industry are free of defects, and working to precisely define how inspection and fabrication capabilities of suppliers can be defined (Walsh et al. 2015). The team's goal was to provide EPC contractors with more information on how to define their own inspection efforts for products with different levels of criticality (and risk) in a project (Neuman et al. 2015, AlMaian et al. 2015). However, as the project progressed, it became clear that a number of factors to define such numbers were missing from the industry, and are not collected by EPC contractors on a regular basis. EPC contractors each have their own ways to define how capable suppliers are, how critical/risky materials are for their projects, and, based on that, gauge how many inspection hours should be assigned to purchase orders. But the industry has no standard way to assign inspection hours and procedures examined by RT308 show that they vary widely between companies.

Despite this scenario, the team decided to develop or adapt some sort of exercise that would capture the challenges of the inspection task, more specifically, and could serve as a basis for discussion on what additional factors need to be taken into account when the inspection effort is defined. Several Lean concepts and principles were considered including, but not limited to, those related to visual management and how they support cycle time reduction during inspections through the elimination of non value-adding activities, and the understanding of what clients (inspectors) value.

This paper describes the process RT308 went through until a simulation was found and adapted to mimic the inspection process in a way that was valuable to the CII membership and beyond. The authors aim to contribute to the discussion that inspection is needed in many cases in our industry and, like other activities, should be properly designed using Lean principles employed to design processes and systems.

RESEARCH METHOD AND TIMELINE

The research method is described in its five phases alongside relevant references used to develop the simulation activity. The literature review and other references are included throughout the narrative to reflect the process the team underwent to develop and test the inspection simulation. The discussion on how the simulation evolved mimics the goals of design science research, where developing, testing, and evaluating an artefact to emulate the inspection process is part of the research process.

PHASE 1 – UNDERSTANDING THE DEFINITION OF THE INSPECTION EFFORT

RT308 had been investigating the problem of non-conformances and the inspection role in improving quality in the products sourced to EPC projects for close to 3 years (Neuman et al. 2015). The previous investigation indicated that the definition of criticality levels of a purchase order (PO), in and by itself or in relation to the project, was a factor to define the inspection levels assigned to POs. Additionally, supplier-specific characteristics were also used to define the effort.

Early in 2015, the team took on a new challenge, which was related to defining fabrication capabilities of suppliers (P_{fab}) and the inspection capability to assure products would be delivered free of defects (P_{insp}) to EPC firms. The work started to be crafted after RT308 presented the results of its original work during CII's 2014 conference, and was approached by practitioners interested in knowing more about how to define these variables. After a review of procedures on how EPC organizations define the criticality levels of the products they acquire and the inspection effort necessary to assure quality products, it became clear that there was no standard procedure available in the industry to define P_{fab} and P_{insp}. The principal investigators (PIs) could identify commonalities regarding the main process and areas surveyed by EPC contractors to evaluate and select suppliers, but not to define the inspection effort assigned to different purchase orders (Alves et al. 2016). Additionally, SMEs indicated that the way data is currently collected at suppliers' facilities and sites might result in non-conformances being under-reported.

Given this scenario, the team discussed the possibility of developing an experiment that could be used to collect data about the inspection capability of inspectors given different scenarios. The team had a lengthy discussion on potential ways to design an educational exercise to illustrate how these factors play a role in the definition of P_{insp}. The goal of the experiment would be to measure data on P_{insp} and the simulation could be used later in CII training events and courses. The PIs were tasked with reviewing the literature on the work of inspectors, as well as on design of live simulations (which are conducted with people as subjects being observed during the simulation). The team identified potential considerations for the simulation:

- Goal: get data about P_{insp} by running this exercise in an environment that can give us powerful insights with minimal risks and high availability. (Versus being in an actual shop and being able to see all that we believe is important to define P_{insp}).
- Sampling: What kind of products/elements will be used in the inspection process? Potentially sampling elements based on different types of inspection required (visual, measurement, procedural, matching).
- Randomness: time and frequency of visits (that defines what will be inspected at the time of the visit – whatever is available at the time of the visit.)
- Other issues: Number of shifts, productivity of the supplier, experience of the inspector (e.g., someone who has been through the simulation before versus a newcomer), information provided to the inspector
- Human and organizational factors: who will participate in the simulation? What matters and needs to be inspected? What are the most critical attributes that need to be inspected? Example: you have 10,000 items that need to be inspected (potentially). You pick the ones you think are most critical but one that might not be critical turns out to impact construction installation.

PHASE 2 – UNDERSTANDING INSPECTION PERFORMANCE

The literature on the inspection activity was reviewed to identify potential ways to address the development of an experiment to collect data on inspection capability (P_{insp}). According to Drury (1992), in his comprehensive paper on inspection performance, the inspection activity is complex and prone to error, making it difficult to design the inspection effort to match a desired level of performance. This also makes the inspection process a prime candidate for study under Lean. Specific functions of inspection in manufacturing include (Drury 1992, p.2282): ensure that a faulty part does not reach the customer, help in defining the state of the manufacturing process, work as a point to capture data about the product and its related manufacturing process. These functions portray the inspection effort as an activity that is aimed to assure customers get the value they expect from products, and also to support continuous improvement through making the manufacturing process transparent by providing data collected during the process.

One way to improve the performance of the inspection activity is by improving the inspector's ability to inspect a product per unit of time, i.e., improving conspicuity (Drury 1992, p.2289). Conspicuity can be improved by making the inspection process to rely on a more visual system that aids inspectors in detecting nonconformances. Visual systems and visual management are topics that have gained increased attention from the Lean Construction literature (Viana et al. 2014, Tezel et al. 2015). Galsworth (2005, p.10) defines a visual workplace as "*a self-ordering, self-explaining, self-regulating, and self-improving environment – where what is supposed to happen does happen, on time, every time, day or night – because of visual solutions.*" A similar approach can be used in designing the inspection task to take advantage of visual aids, color-coding, instructions and procedures, list of potential defects, an uncluttered work area where inspection is performed, gauges, and *poka-yokes* (fool-proof devices), to name a few. Visual systems should help "*improve the discriminability between imperfection and a standard*" (Drury 1992, 2291) to help the inspectors in making the right decisions.

During the inspection activity, at least four major characteristics that influence the performance of the inspector have to be taken into account (Drury 1992):

- Accuracy – the inspector should make the correct decision on the majority of the components/characteristics inspected.
- Speed – inspection should be timely in capturing non-conformances and avoiding them to continue to exist or propagate throughout a process. Additionally, there is always a trade-off involving how fast an inspector works versus how many nonconformances can be caught.
- Flexibility – the inspection effort must be able to deal with multiple types of potential nonconformances and give them proper disposition.
- Stability – devices being used during the inspection activity should remain stable and not need constant recalibration. In a similar fashion, inspectors should face, to the extent possible, stable conditions to develop their task.

These characteristics turned out to be extremely relevant during the discussions about the design of an experiment or a simulation that could be replicated for educational purposes. Should the team decide to develop an experiment, a set of products and equipment would have to be maintained in pristine conditions so that the experiment could be replicated multiple times in a controlled environment under similar conditions. This would require a laboratory type of setting where volunteers would participate in the experiment and data would be collected about that. Alternatively, a simulation activity could be developed and widely replicated for educational purposes but it would be more difficult to come up with precise numbers about the inspection capability of a group of inspectors.

Task Analysis of Inspection and its Outcomes

The inspection task can be divided into four major steps: present the items for inspection, search the item to locate nonconformances, decide on the appropriate categorization for the non-conformance, and take action to accept or reject the item (Drury 1978). Furthermore, Wang and Drury (1989, p.181-190) have identified the following subtasks that are part of the inspection task, and related them to the major type of skill necessary to perform each subtask: orient the item (manual), search the item (perceptual), detect a flaw (perceptual), recognize/classify item (perceptual), decide status of item (perceptual), dispatch item (manual), and record of information about item (manual and perceptual). Based on their research, and given that most of the tasks related to the inspection task are perceptual and subject to human error, research on inspection has consistently found large differences among inspectors.

Finally, the inspection task is not complete without the final disposition of the item and its categorization into one of the four states indicated in Table 1. An item can be correctly accepted or rejected (true-positive and true-negative) or incorrectly accepted or rejected (false-positive or false-negative). At the end of this phase, the challenges related to the inspection task and important issues to be addressed in an experiment or simulation become more defined. The issues discussed in this section formed the basis of the simulation activity adopted by the team.

Table 1 – Inspection Decisions and outcomes (Adapted from Drury 1992, p.2286)

Inspection Decision	True State of Item	
	Conforming	Nonconforming
Accept	Correct accept (True-Positive)	Miss (False-Positive)
Reject	False alarm (False-Negative)	Hit (True-Negative)

Phase 3 – Examples of Existing Inspection Experiments and Factors/Metrics Modeled

During this phase, RT308 searched the literature for examples of experiments and simulations involving the inspection task, or examples that could be adapted to support the goals of the team to mimic the inspection task. The literature revealed not only what types of experiments and/or simulations could be developed but also which characteristics of the inspection task were often mimicked and had their results quantified.

The ability of inspectors to correctly categorize an item is impacted by many factors which include, but are not limited to: the training they receive (Drury 1992); physical, personnel and organizational factors (Drury 1992); their skills in terms of attention, perception, detection, recognition, memory, judgement (Drury 1978, Wand and Drury 1989); and the payoffs related to the task (Chi and Drury 1998).

Wang and Drury (1989) used different tests used to evaluate inspectors' performance (circuit pattern inspection, computer-generated symbols, and color video comparator) by comparing the following performance measures: search time (time to locate a fault), ending time (time to define that an item had no fault, and the item was good), search error rate (probability of failing to identify a fault), decision error rate (probability of locating a fault, but categorizing it incorrectly), and overall error rate (resulting probability of making the wrong decision). Their study indicates potential metrics that could be used in the design of an experiment or simulation.

Chi and Drury (1998) conducted a controlled experiment to observe the performance of ten subjects who examined computer-generated integrated circuit boards chips, under varying conditions. The variables that made up the scenarios included: defect rates, values of accepting/rejecting good/faulty items, cost of accepting/rejecting good/faulty items, time to make a decision, and the probabilities of accepting/rejecting a good item. Those authors asked the inspectors about the criteria they had used to make a decision about the items. What they discovered was that inspectors would change their inspection criteria based on different payoff conditions.

In another experiment, Drury and Sinclair (1983) investigated indicators related to hit rate (percentage of faulty items rejects) and false-alarm rate (percentage of good items rejected) of inspection of cylinders performed by experienced inspectors and a prototype of an inspection device. They found out that inspectors performed better than the machine because they could differentiate small flaws that would not render items unacceptable. One interesting insight from this paper was the importance of keeping items in pristine condition throughout the experiment. Additionally, factors affecting the inspection task to assure reliable results would need to be tightly controlled, e.g., using the same defect types and their severity, assuring randomness of the factors involved during the test (Drury 1992). Assuring that the defects and their frequency remains the same would be necessary to avoid having inspectors find new nonconformances along the way because of the way items were handled through the experiment. This challenge turned to be a big red flag for RT308 in that if the team adopted this option the approach would be limited to a controlled environment and/or items versus being widely available to CII members.

In a large experiment conducted at Microsoft by Carver et al. (2008), 70 subjects were requested to inspect a document (loan arranger), find, categorize, and record six different defect types (omission, ambiguous information, inconsistent information, incorrect fact, extraneous, miscellaneous) to evaluate the relationship between inspectors' background and the effectiveness of their decision. Carver et al. (2008) defined effectiveness as the dependent variable, and educational background, educational degree, industrial experience, requirements experience, and inspection experience as the independent variables. They found that level of education, prior industry experience, and other job-related experiences did not impact the effectiveness of the inspector. However, subjects who had experience in writing requirements performed statistically better (found more defects) than the other participants. This experiment highlights the importance of having an artefact that will not be changed throughout the experiment, is easy to replicate, and contains a specific list of known nonconformances beforehand.

Fen and Drury (2010) recruited ten male engineering graduate students, and paid them to participate in training and practice sessions using images in a computer display. Subjects were asked at the end of the experiment to report their search and decision-making strategies. They found that subjects would stop the search after some time searching, and varied their decision criteria depending on the pay structure.

The main lesson learned from the literature review was that the design of an experiment would work to be tested in a controlled environment but its educational impact in the EPC industry would be limited due to the challenges related to its replication in training sessions. Additionally, it would be hard to keep the artefacts reviewed always in the same conditions that they had in the beginning of the experiment. That said, the authors started the discussion about developing a new simulation or searching for examples that could be adapted to mimic inspection in the EPC industry.

PHASE 4 – ADAPTING AN EXISTING SIMULATION

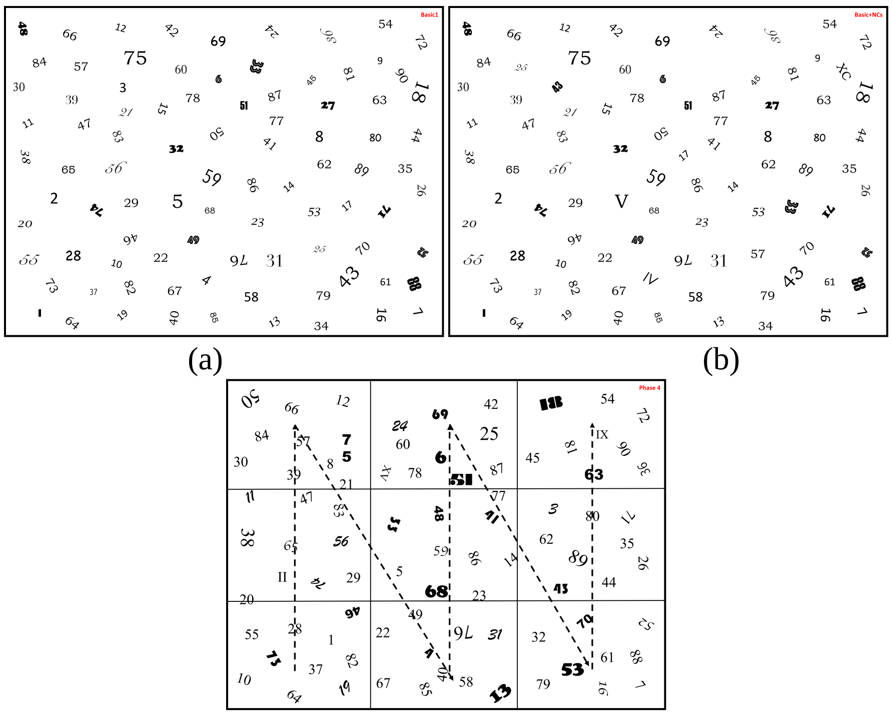
The outcomes of each phase were presented to the team during six months of literature search and discussion. At every step, the SMEs would provide comments that steered the PIs towards the most appropriate solution to this task. At this phase, the team was convinced that developing a simulation would be more beneficial, as it would serve as an educational tool about the inspection process, even if precise numbers to estimate P_{fab} and P_{insp} would not result from the simulation. Around the five-month mark, while searching for existing simulation activities, the PIs came across the 5S numbers game (Superteams 2015). The 5S game was a simple paper and pen version of an existing simulation that was considered a viable alternative to accomplish the goal of educating the industry about the challenges of the inspection effort. The next step in adapting this simulation to mimic the inspection task was to include technical terminology familiar to the EPC industry to make the simulation more appealing and educational to those involved.

The 5S game in its original format addresses the fact that organized and neat environment is conducive to higher productivity, and that a cluttered and disorganized environment slows people down and results in lower productivity levels. This illustrates Lean principles clearly. Participants are given 30 seconds and asked to search for numbers 1 through 50 in a letter-size paper showing the numbers in a disorganized format (different font types and sizes, numbers oriented in different directions, and numbers 1 through 90 printed on the paper). At the end of each 30-second period, participants are asked to indicate the highest number they found in sequence. During the different rounds of the simulation, participants discuss the challenges of each phase, and use one of the 5Ss to improve the organization of the numbers printed, which result in higher productivity at every round.

The team conducted the original version of the 5S game in a face-to-face meeting and discussed how it could potentially be adapted to reflect the challenges of the inspection process. One of the main points team members pointed out was that the 5S game process seemed very similar to an inspection task, however, it did not address the fact nonconformances might be found along the way. After multiple rounds of discussion and interactions some rules where defined for the first version of the inspection simulation.

Including Nonconformances and Defining the Rules

The first version of the inspection simulation used two basic sheets represented in Figure 1. Figure 1(a) shows the sheet used in Round 1 of the simulation where Arabic numerals (1-90) are dispersed throughout the page, and participants were given 30 seconds to find the numbers, and report at the end of the period the highest number found and the challenges they faced. Participants were instructed to strike through the numbers they found in sequence, that is number 4 could not be struck through unless numbers 1 through 3 had been found in order, and circle any number that was considered a non-conformance.



(a) (b) (c)

Figure 1: Letter size sheets with: (a) Only Arabic numerals printed; (b) Arabic and Roman numerals printed, missing numbers; (c) Sequence of numbers shown

In Round 2, participants were given the same instructions, but this time some numbers were missing and Roman numerals were introduced in substitution for some of the numbers (e.g., the number 5 was written as V), both instances should be considered as nonconformances. The sheet shown in Figure 1(b) was used. However, during the original version of Round 2, participants were not instructed about the missing numbers and the Roman numerals, they were just told that there could be nonconformances on the sheet they were given for Round 2 introducing some complexity to the task. During Round 3, participants underwent a discussion about potential nonconformances and what they would look like; this tried to mimic a pre-inspection meeting between the inspection team, the customer, and the supplier. The sheet on Figure 1(b) was once again used. Finally, during Round 4, participants were told that the numbers were organized on a grid format as shown in Figure 1(c), and that the numbers were organized in sequence following the order shown by the arrows on Figure 1(c), e.g., number 1 should be on the lower left section, number 2 should be in the section right above it and so on. Numbers missing from the correct quadrant or misplaced were also to be considered as nonconformances. At the end of each of the four rounds participants were asked: 1. Which was the highest number you could “strike through?”; 2. Was there enough time to “inspect” numbers 1 through 50?; 3. Did you find any non-conformances? How many?; 4. What challenges have you found while trying to find the numbers?; 5. How do these challenges impact inspection?

PHASE 5 – TESTING THE SIMULATION

RT308 members tested initial versions of the inspection simulation in different settings over a period of three months. During the testing phase, team members conducted the simulation with students and practitioners and collected their feedback about the simulation to fine-tune how the sheets should look like, and what kind of instructions should be available to the facilitator. The feedback was analyzed by the team and incorporated as the team saw fit. The feedback about the simulation per se was mostly positive and it showed that the level of complexity involved in the process was adequate to achieve the team’s goals. Some of the comments were related to: time pressures (keep looking for a number or assume it is missing and it is a non-conformance), vague instructions regarding what they should be looking for and learning about nonconformances on the go (if a number appears twice or in a different area of the grid, how should I categorize it?), searching/inspecting multiple attributes in a disorganized environment is very time consuming, understanding how the system (numbers) is organized results in an improvement in productivity. The current version of the inspection simulation also requests participants to collect data about variables related to the inspection decision and the state of the item, as shown in Table 1, to start building a database of numbers that might reveal relationships between speed and accuracy, and how that varies across different rounds. The facilitator of the simulation is now given instructions about the types and numbers of nonconformaces in each phase and share that with participants, who collected data throughout the simulation. Then, participants can compare what they got in terms true positives/negatives, and false positives/negatives, and benchmark their results against those kept by the facilitator and other participants.

CONCLUSIONS

The paper described the journey of a team to develop a simulation activity that could mimic characteristics of the inspection process outlined in the literature and suggested by a group of subject matter experts. The final version of the simulation captures important challenges (and complexity) related to the inspection activity such as: the trade-off between accuracy and speed, flexibility to deal with different scenarios and items to inspect, the existence of false positives and false negatives, and the importance of an organized environment and clear set of instructions to successfully complete the inspection task. Feedback collected from participants during the development and trial stages overwhelmingly suggest that this simulation is a good instrument to educate people about the challenges associated with the inspection task and many indicated that it made them better understand and gain an appreciation for inspectors tasks.

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