CUE-BASED DECISION-MAKING IN CONSTRUCTION: AN AGENT-BASED MODELING APPROACH

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ABSTRACT

Workers on a construction site face many ambiguities when executing operations at the workface. While they will have received instructions through communications, whether of written (e.g., an engineering drawing; specifications; etc.) and/or oral, about what they are supposed to do once at the workface, they still are required to make a judgment on what will be done and how. This research posits that the more explicit the work instructions the less likely workers will mistakenly execute assignments. We distinguish work instructions based on whether the worker is given clear visual 'signals' (e.g., a solid red traffic light) as opposed to having to rely on visual 'cues' (e.g., a blinking red traffic light). To test this hypothesis, we investigate how the two different instruction types influence performance of a construction worker during assignment execution. An Agent-Based Modeling (ABM) approach was employed. This enabled us to experiment with different types of instructions to a worker, which in turn allowed observing patterns of behavior and responses to a signal versus a cue. An agent (worker) is introduced to two different environments: One environment directs an agent towards a predetermined destination by utilizing explicit instructions (signals); the other environment uses an agent with same knowledge level as in the first environment but only has implicit instructions to follow (cues). Preliminary modeling focused on one key measure: Performance effectiveness. Compared to the explicit instructions case, outcomes using the implicit instructions environment, i.e. following cues, resulted in a probability of only 38 percent in satisfying a required deliverable (performance effectiveness).

KEYWORDS: Cue-based Decision-Making, Performance Effectiveness

INTRODUCTION

A definition of Lean Construction states that it is: "A holistic facility design and delivery philosophy with an overarching aim of maximizing value to all stakeholders through systematic, synergistic, and continuous improvements in the contractual arrangements, the product design, the construction process design and methods selection, the supply chain, and the workflow reliability of site operations," (Abdelhamid et al. 2008). The Lean paradigm is heavily invested in planning upcoming work (Koskela 2000). As part of the Last Planner® System (LPS®), Make Ready or Lookahead planning facilitates onsite production assignments. These are

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established based on the ability to complete weekly work assignments. To measure the effectiveness of the site crew and management to carryout assignments (commitments) the Percent Plan Complete (PPC) is calculated. The PPC metric is found by dividing the number of actual completions by the number of planned completions. The PPC ranges from 0 to 100% and reflects both the effectiveness of production planning and the reliability of workflow from one trade to another (Ballard & Howell 1994a; Ballard & Howell, 1994b; Ballard 2000; and Salem et. al, 2005). Under the Lean Construction paradigm, increasing planning reliability increases system throughput, which is the rate of production or output. PPC is considered the critical performance measure of a production system as opposed to the focus on point speed in conventional construction management where point speed is typically increased by maximizing capacity utilization.

Using LPS® as a planning tool uncovers a myriad of constraints that threatens the execution of assignments as well as production progress. By removing these constraints, Last Planners are more confident in making and keeping their commitments (Jayaraman et al 2008).

Production problems will still occur because effective communication protocols deployed throughout execution of a project are a major challenge. Logically, continuous communication among construction project members has a direct influence on the process and certainly advantageous to realizing higher performance and reliable movement of construction operations (Shohet and Frydman 2003).

Communication may be categorized in two major divisions: formal and informal (Orlikowski and Repetorie 1994). Engineering drawings and specifications are an example of formal communication. Examples of informal communication include oral exchanges, face-to-face interactions, and inferences made based on the physical environment (taking cues from the surroundings). The critical role of informal communication in construction project execution effectiveness has been demonstrated elsewhere (Shohet and Laufer 1991, Wang and Liu 2009). One of the key issues is how successful the communication is to share intent and assist resources in accomplishing that intent.

This paper considers the question of the impact that absence of formal communication, as well as verbal communication, will have on production performance. When formal communication is absent, we posit that a worker will resort to making inferences from the visual cues around her/him. These inferences represent a challenging decision-making process; does one proceed with the work or wait and verify? A visual cue may be misleading and bring about what-if scenarios, increasing the likelihood of endangering the worker, crew, and even project outcomes, let alone the amount of rework, and generally waste. One solution to this problem is to strictly execute work based on formal communications. However, this may slow down the pace unnecessarily. We do not understand the impact that an inference from visual cues has on work execution to make this judgement. This paper attempts to quantify this impact and not only qualitatively describe it.

APPROACH

For a construction worker, a formal communication medium is more of an explicit signal to act in a certain way. An informal communication holds the potential of being vague or subject to interpretations. This research posits that the more explicit the work instructions the less likely workers will mistakenly execute assignments. We distinguish work instructions based on whether the worker is given clear visual 'signals' (e.g., a solid red traffic light) as opposed to having to rely on visual 'cues' (e.g., a blinking red traffic light). To test this hypothesis, we investigate how the two different instruction types influence performance of a construction worker during assignment execution.

An Agent-Based Model (ABM) is employed to investigate how a worker behaves when clear communication symbol is provided versus a situation when it is not. Agent-Based Modeling (ABM) is a simulation method in which a set of decision-making entities, i.e. agents, constantly evaluate their surrounding environments and stochastically make decision in accordance with specific rules to which they have been introduced (Sawhney and Walsh 2003). As dynamic as a construction job site is, it is difficult to understand different aspects of an emergent occurrence and predict how changes in a phenomena may impact group behaviour. An ABM can comfortably exhibit complex behaviour and provide information about the dynamic of such a system (Bonabeau 2002).

An agent is introduced to an environment as its user: one environment directs an agent S ('S' symbolizes signals or signs) towards a predetermined destination by utilizing clear directions to required actions – almost robot like. The other environment experiments with agent C ('C' symbolizes cues) that has the same knowledge and ability to make decisions as agent S does.

MODEL INFORMATION

In the job site environment mentioned, there are two pre-arranged locations: a start point and a finish point. These points have been positioned in a conventional south and north directions of the job site, respectively. Both agent S and agent C are asked to travel from the start point to the finish point. This symbolizes accomplishing work tasks along that path.

In job site where agent S lives, signs have specific meanings (Figure 1):

- ***Blue***: Move straight forward [move towards north direction]
- ***Orange***: Make right-turn [move towards east direction]
- ***Brown***: Make left-turn [Move towards west direction]

By contrast, agent C works in a job site that does not provide clear expressions. Therefore, directions may be interpreted in a subjective manner:

- ***Blue***: Move straight forward
- ***Orange***: Make right-turn
- ***Brown***: Make left-turn

Both environments have certain unambiguous indicators positioned randomly in the gird:

- ***White***: Path way
- ***Gray***: Wall [stop moving – it is a dead-end!]
- ***Green***: Start point

- ***Red***: Finish point [Stop moving – it is the destination!]

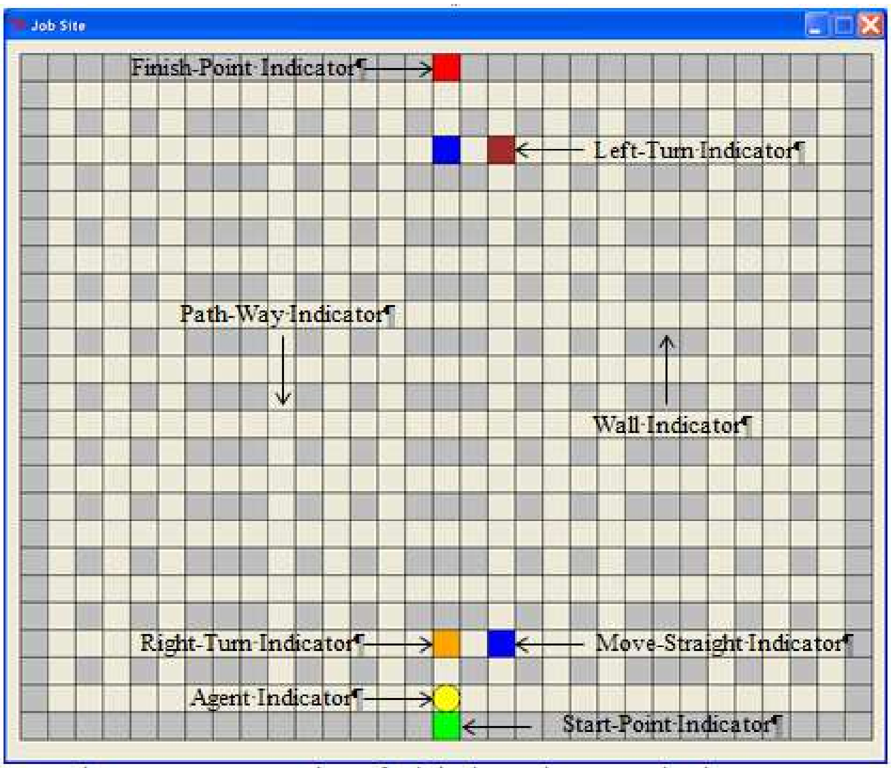

Figure 1: Representation of the job site under investigation and communication signals to workers (agents S and C)

It is important to note that, in both of environments, a blue sign orders an agent to move straight forward. Yet, only agent S is programmed to go toward the north of the job site, while agent C may interpret the 'cue' to mean head in the north direction relative to the current position it is in (meaning go straight). Similar interpretations were incorporated in other cues that agent C will read.

As part of model development, both agent S and C were programmed to comply with few regulations:

- Agent S interacts solely with explicit signs. These signs explicitly convey required actions to agent S (which direction it needs to move in order to reach finish point).
- Agent C interacts solely with implicit signs. Therefore, agent C does not clearly know what a sign exactly means. Basically, agent C does not get explicit directions on where to move to next. Agent C has to 'interpret' the cue given and exercise decision-making based upon her/his existing situation.
- It is assumed that agent S and agent C are not allowed to revisit any sub-site through which a move had been made. Also, for simplicity, an agent NEVER looks towards the south direction (down). Thus, only three out of four possible directions are available to an agent to move (north, east, and west).

- In a situation where no sign exits, both agent S and C are required to move only towards the north of the job site. Such a scenario, however, would not be applicable to agent S since it always knows what exactly to do.
- In the process of experimentation, it is assumed that both explicit and implicit signs are correct with respect to content, while the efficiency of following them is not known and will be measured. That is, a sign is effective enough to move an agent towards a direction yet may not be efficient as it may not be leading to the shortest route. These are not 'smart signals'.

MODEL OPERATION

Consider a job site as illustrated in Figure 2: an agent, represented in a yellow circle, is required to travel from a start to a finish point. Prior to making the 'trek', an agent identifies its neighbors to obtain information as to direction for its movement. As a move is made, the agent remembers its previous sub-site as a wall to satisfy the rule that it cannot revisit an area which it has already visited.

Agent S simply recognizes explicit indicators and immediately follows them to reach its destination. Agent C, on the other hand, decides upon its next step considering existing implicit expressions and a random selection. That is, when it encounters a three-way path option (forks) while moving, agent C randomly picks its choice out of the three available possibilities. In fact, whether or not a signal offers a direction of movement, agent C will trust its decision-making and take a direction to move (output data from the job site examination showed this very scenario). Such decision-making manifests a one-third chance of proceeding into a correct path.

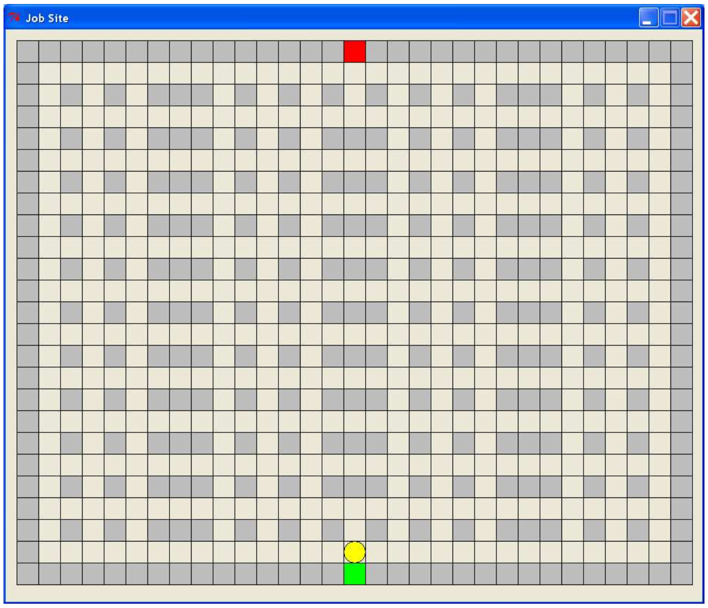

Figure 2: Schematic Representation of a simple job site

It is possible that Agent C will make a set of decisions until it recognizes it has no place to move:

- Walls in at least two directions while agent C moves towards east of job site

- Walls in at least two directions while agent C moves towards west of job site
- Walls in all three possible directions of movement

This represents a trial where agent C has reached a dead-end and failed to accomplish its assigned duty. It is important to note that decision-making practiced in each trial by agent C will be independent of previous trials – Agent C has no memory of prior experiences, and, hence, is not learning to get better. Perhaps our use of the term "decision-making" would sound more reasonable if agent C was learning throughout each of its experimentations. Nevertheless, the presented model may be counted as a positive start for further investigations.

In the meantime, it seems important to emphasize that different signs with which an agent interacts in environment S intend to represent explicit instructions; e.g., a well detailed construction drawing, a worker receives in a construction job site rather than interacting with implicit signage in the workplace.

OUTCOMES AND DISCUSSION

A simple and a complex representation of a job site were introduced to both agent S and agent C. As can be observed, a simple job site is shown in Figure 2, and offers an agent no signal as to an anticipated finish point whereas a complex job site, shown in Figure 3, offers many possible indicators for an agent to walk towards a destination.

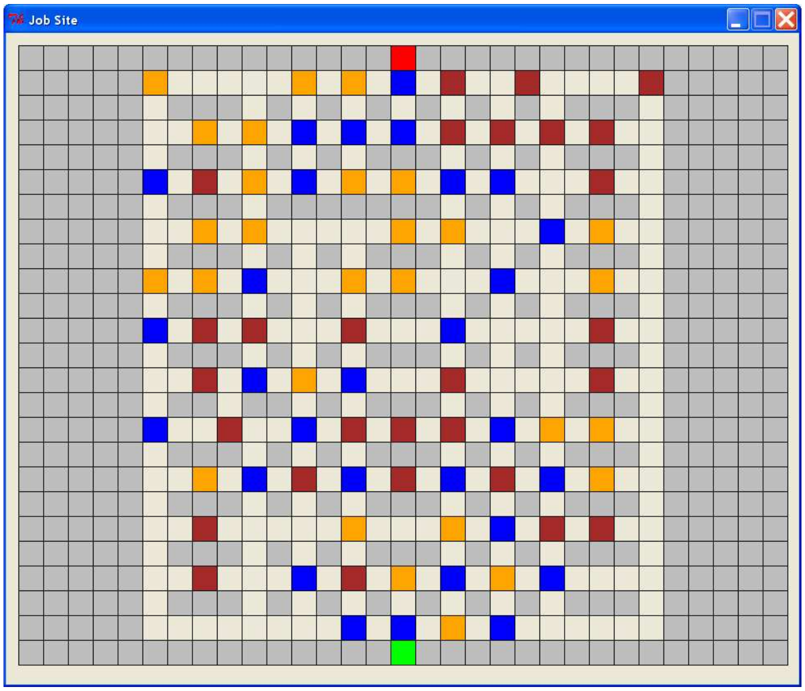

Figure 3: Representation of a complex job site

Five-hundred trials were examined in each of the simple and the complex job site. For the one-thousand experimentation runs, the number of failures was counted against the successes. The outcomes did not vary significantly as represented in Figures 4 and 5.

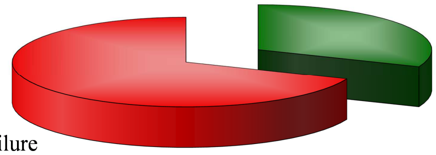

Figure 4: Success against failure – agent C performance at simple job site

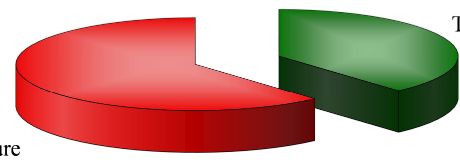

Figure 5: Success against failure – agent C performance at complex job site

To measure efficiency of Agent C's decision-making process, or the cost of not having explicit communication, as discussed in earlier paragraphs, the number of cells between which it travelled or, in other words, number of moves it made to reach the finish point from the start point were compared against that accomplished by agent S - assuming agent S has experienced the higher efficiency of the two agents by following explicit symbols. Figures 6 and 7, summarize the results for both agents (number of moves versus the trial number).

As Figures 6 and 7 show, Agent C's performance (number of moves) are higher on average compared to Agent S. The results are also rather scattered, showing high variation, for Agent C. Interestingly, the performance of Agent C was better in the complex job site than it was in the simple job site. The high number of repetitions tells us it is reasonable to accept this inference. To explain why this happened, two plausible interpretations are possible, and our reader may have more or other views. First, it appears the presence of more signals in the complex job site offered agent C better options as to its moving choices. Therefore, there was an overall improvement in performance efficiency and the number of successes. Second, considering the complex job site, we may have not chosen the best path for agent S to use, albeit it was randomly selected.

In the simple job site case, performance efficiency of agent S is less likely to be of any doubt – the best path was clear. Thus, it can be concluded that agent C has reacted in a more-random manner to find its route to an assigned finish point, in the absence of signals (explicit or implicit). Consequently, performance efficiency of agent C has dropped and its path of choice has more often reached a dead-end.

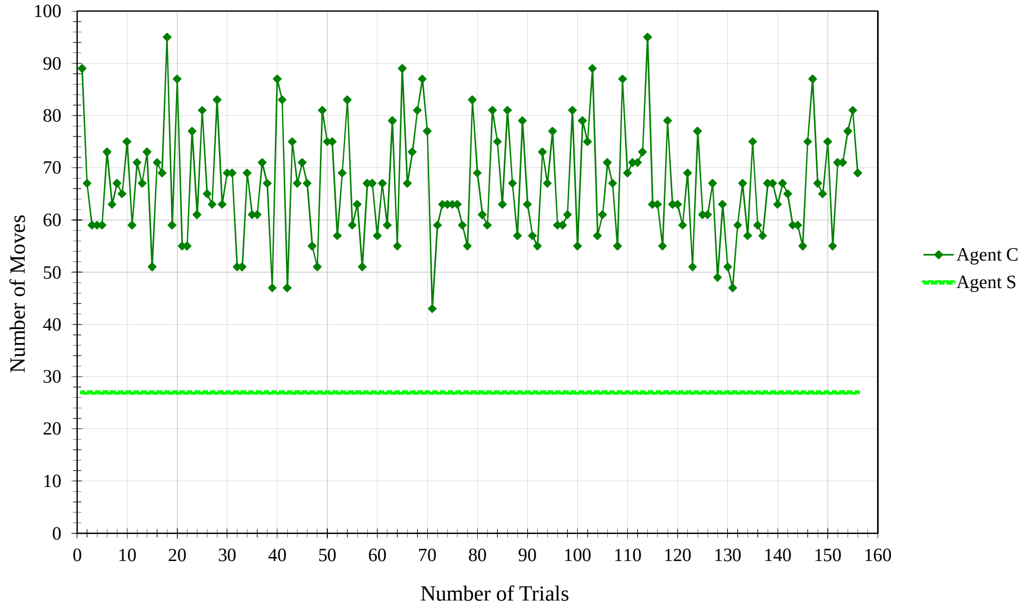

Figure 6: Efficiency performance – agent S versus agent C – simple job site

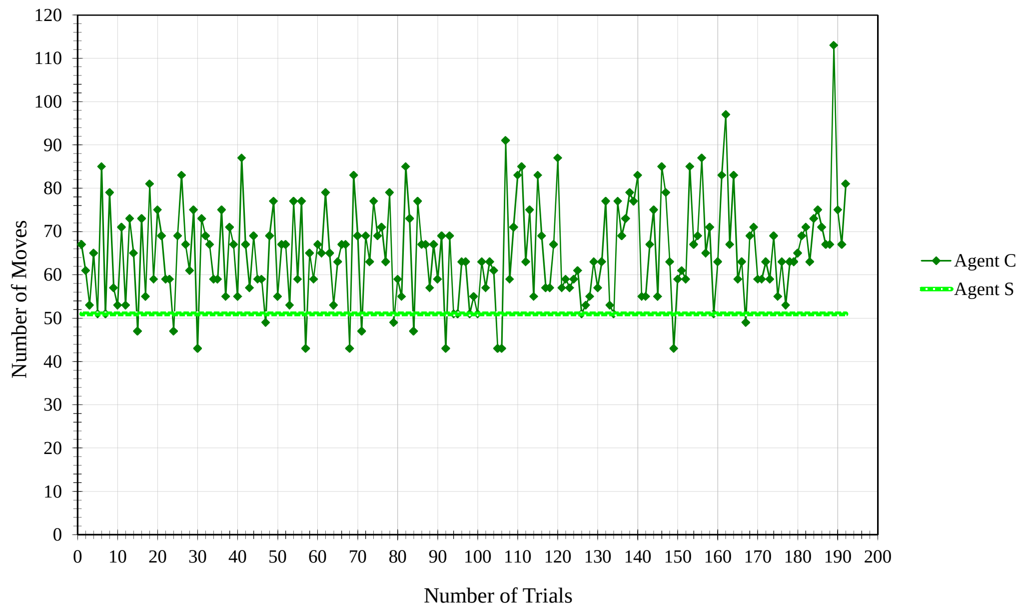

Figure 7: Efficiency performance – agent S versus agent C – complex job site

The outcomes using the implicit instructions environment, i.e., following cues, resulted in a probability of only 38 percent in satisfying a required deliverable (performance effectiveness). The prima facie results indicate that explicit instructions will result in better outcomes compared to letting workers interpret cues in the workplace. It is still early to make concrete recommendations from this research with respect to whether the cost involved in providing explicit signals will be off-set by the saving made in performance with explicit instructions.

FURTHER IMPROVEMENT

In future work, incorporation of cost into the modeling will make the model closer to reality and allows us to better understand the impact of sacrifice judgments related to making instructions more explicit. Additional development is also needed in several aspects in order to reach more understanding of behavior of agents in environments requiring inference from cues. For example, how learning affects the decision-making experience of the agent. In addition, agent characteristics such as experience and skill levels introduce another level of complexity while possibly gaining more understanding of the visual cue interpretation phenomena.

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