

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

By

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ABSTRACT

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A construction worker often faces ambiguities as he/she executes an operation to deliver an assigned task. Ambiguities may be induced by a broken communication process (e.g., an incomplete construction drawing; an implicit verbal instruction), in which a recipient (e.g., a skilled trade worker) does not receive perfect information and explicit instruction. In such circumstance the receiver of this imperfect information is required to make a judgment on ‘what-to’ do and ‘how-to’ do it.

This investigation suggests that the more perfect/explicit the instruction is the more efficient the execution will be – measured in terms of the reduced task duration and need for re-work. Perfectness and imperfectness of an instruction in this study is distinguished based on whether it is an explicit signal (e.g., a solid red traffic light) as opposed to an implicit ‘cues’ (e.g., an alternating orange/green blinking traffic light). This hypothesis is evaluated based on impact of these two instructions types on performance efficiency of a construction skilled trade worker while executing an assignment.

An Agent-Based Modeling (ABM) approach was employed and different types of instructions were introduced to an agent. The outcomes suggest that performance efficiency is correlated with level of instruction provided which can improve performance efficiency up to 78 percent.

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I would like to dedicate this effort, if is worth to be devoted, to Dr. Mahmood M. Moallemian – a man of few words who, as a great friend, parented the newly-born life of mine in United States of America. I am, for life, in debt of his kindness.

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(1.0) Chapter One – Introduction

Communication is generally defined as exchange of information among a group of at least two participants. The information flows from one participant – i.e., sender – to another participant – i.e., receiver. Such exchange happens irrespective of how accurate a piece of information is, or whether it was in fact received accurately by the intended receiver. It, however, is of great importance if a piece of information is properly received in the exact manner its sender intended it to be received. In other words, it is important if communication has properly exchanged a piece of information; and for that matter, if the receiver has captured the desired information – correct or incorrect – which was meant to be communicated (Management Study Guide, 2008). This dynamic is so critical on construction jobs and will be presented through an example case, which underscores the problem this research focused on exploring and investigating.

In the process of alteration in an office building, mechanical utilities such as hot-water and chilled-water pipes were planned to be re-worked in order to accommodate the needs of a renovated space. Being an aged facility, a portion of pipe insulation material was contaminated with asbestos, a biohazard mineral substance. An asbestos abatement contractor was hired to properly demolish and safely abate such insulating material. Considering the cost of setup, abatement, and disposal, the project manager decided to assign the asbestos abatement sub-contractor to demolish both asbestos- and non-asbestos contaminated pipe insulation materials. Therefore, in the work-order, the asbestos abatement sub-contractor was requested to suitably remove and carefully dispose ‘all’ pipe insulation material on job site. The asbestos abatement sub-contractor delivered the work requested while only asbestos-contained insulation material was abated and pipes with non-asbestos insulation material remained insulated.

The following two questions arise:

(a) Was the correct information communicated between the client and subcontractor? It was indeed – The asbestos abatement sub-contractor properly demolished and safely abated pipes that had the asbestos insulation material; and (b) did the receiver capture the desired information? In this case the sub-contractor did not – The project manager intention was to have the asbestos abatement sub-contractor remove and properly dispose of every piece of pipe insulation material whether or not it contained asbestos.

The project manager did communicate with the asbestos abatement sub-contractor, yet the communication was not clear enough for the sub-contractor to deliver the project manager's desired outcome. On the hand, the sub-contractor, being an asbestos abettor, definitely delivered its assumed task by properly removing asbestos contaminated pipe insulating materials – i.e., according to the legal contract, such a sub-contractor is assigned for demolition of hazardous asbestos material. Thus, it can be fairly concluded that while in this communication process a piece of information flowed from its sender to its intended recipient, it was not effective enough to convey desired outcomes.

A 'precise and crisp' piece of information provides effectiveness in communication (Management Study Guide, 2008). An abstract and unclear instruction, on the other hand, creates misunderstanding and brings about confusion. Had the project manager in the abovementioned scenario clearly instructed the sub-contractor as to the required deliverable instead of using somewhat abstracted information represented in the word 'all', he would have eliminated chances of misunderstanding and its subsequent errors.

(1.1) Problem Area

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

A construction project is technically planned in pre-construction and this plan is refined during construction. An incomplete design or any other directive (i.e., an instruction) in pre-construction usually leads to a wrong execution in construction which in turn may complicate delivery of a project. Among other resources and inputs, a construction activity requires two critical elements: *information* as to ‘*what-to*’, and *instruction* as to ‘*how-to*’ something will be built/installed. This thesis posits that information in the form of ‘*what-to*’ affects execution effectiveness and ‘*how-to*’ instruction influences execution efficiency.

As one of the project’s participants, a skilled trade worker will be expected to conduct and complete a construction-related task in a job site in accordance with a set of instruction. Such instruction – formal and informal – is often presented in the form of specifications, work-scope documents, drawings, work orders (written and oral), and the like.

An instruction provided on a construction job site (usually extracted from construction documents and drawings) needs to offer a clear illustration of how a task or assignment is to be successfully executed. In other words, a clear instruction and an effective directive provide sufficient amount of information (i.e., ‘*how-to*’) which is required to perform a task (i.e., ‘*what-*

to'). The product of such an instruction will result eventually in the expected deliverable/outcome.

A clear instruction is readily understandable and does not require extensive studying; it is simply detailed and offers close to flawless communication to its executer. Hence, performance will meet the intended deliverable. For that matter, level of explicitness of a given instruction and a directive is one of the parameters which greatly govern the accuracy of a task deliverable because an explicit instruction will limit, if not eliminate, likelihood of misinterpreting a directive.

This thesis is focused on incompleteness/imperfectness of a piece of information – a sender in communication process shares an incomplete piece of information which is comprehended by its receiver exactly as is; or the receiver interprets an absolutely perfect message (as its sender assumes) to be perfect. These two (general) cases often conclude in a common outcome: a wasteful effort. Delay in schedule performance and cost-overrun are two examples of cost such a waste. Such an expense can hinder project performance by a factor of two (2) at the least.

Resources are utilized to deliver an assignment. If this assignment is not delivered as anticipated due incompleteness/imperfectness of information, then more resource will have to be utilized in order to accomplish the same assignment correctly – i.e., undo a wrong-do and re-do for a right-do. This exceeding quantity of utilized resources can introduce as least as three (3) times budget-over run and two (2) times task duration delay for what is allocated to such an assignment – let alone its impact on schedule performance. Thus, it is importance to understand impact that ccue interpretation imposes on project performance, even in order of magnitude comparison as in this investigation.

(1.2) Goal

The goal of this thesis is to understand the impact that absence of instruction will have on production performance at the workplace. As with any goal statement, this is not reachable but rather possible to approach.

This investigation will focus on the situation when execution instruction is absent in varying degrees up to a hypothetical worst case scenario which is to have no instructions at all. The thesis makes the assumption that a construction worker will resort to making inferences from the visual cues of her/his surroundings. A cue may be misleading and/or bringing about further what-if scenarios to contend with increasing the likelihood of endangering the worker, crew, and even project outcomes, let alone the amount of re-work, and generally waste.

These inferences represent a challenging decision-making process; does one proceed with the work or wait and verify? One solution to this problem is to strictly execute work based on formal communications of clear instruction. However, this may slow down the pace unnecessarily. The impact that an inference from visual cues has on work execution is not understood, and certainly not quantified with respect to time or cost, to make this judgment.

(1.3) Objective

This thesis attempts to quantify and qualitatively describe the impact of interpretation of cues on execution of a construction activity and delivery of its expected outcome. In order to meet the thesis aim, an Agent-Based Model, as described in Chapter Three (3), was developed to represent a construction job site environment. Experiments were then conducted to understand the effect of '*what-to*' and '*how-to*' on execution and delivery of a construction assignment.

The objectives to approach the stated thesis goal are:

- (i) Developing a conceptual model for a situation in the workplace in which a skilled trade worker is required to interpret a cue and make a decision;
- (ii) Developing an ABM computer-based simulation for cue interpretation at the workplace on a virtual construction job site; and
- (iii) Conducting simulation-based experiments to study cue interpretation at the workplace and its impact on work performance

(1.4) Scope

In this thesis, exploration of a cue interpretation in construction was bound by construction project execution level and investigation focused on a construction execution activity – an agent in the developed Agent-based Model simulated a construction skilled trade worker which would respond to an instruction and represented accomplishment of a construction project activity.

Impact of cue interpretation on performance of such an agent – i.e., a construction skilled worker – was measured based on the excessive time of completing a nominal task – amount of time which an agent spent to either: i) understand a ‘what-to’ do and realize its ‘how-to’ do; or ii) re-work its wrongly interpreted ‘what-to’ do. It is important to note that, due to complexity involved, influence of imperfect instruction on quality of a delivered activity and its associated cost were not defined in scope of this investigation.

Demonstrated cases – in Chapter 4; Section 4.3 – are examples observed in different construction projects site on campus of Michigan State University by author of this investigation through his

job responsibilities in Infrastructure Planning and Facilities. Note these examples, by no means, are proof of a concept; rather a few instances which demonstrate how cue interpretation is widely spread in construction job sites.

(1.5) Thesis overview

This thesis is written in five (5) main chapters. In Chapter One (1), the motivation, goal, and objectives for this investigation is presented. Chapter Two (2) presents the literature on communication in a construction project as it pertains to task execution. A brief overview of Agent-Based Modeling (ABM) is also provided. The research method is reviewed in Chapter Three (3). Chapter Four (4) outlines results of the computer simulation for multiple repetitions of different task completion scenarios. The modeling is then evaluated with examples which have been observed in different construction projects and findings are discussed. In the last chapter, Chapter Five (5), conclusions to the research and contribution to knowledge and industry are discussed as well as limitations and future research.

(2.0) Chapter Two – Background

Communication is indeed inevitable in our daily routine – in our personal lives and in our professional businesses. It is an essential activity in most of human interactions (Orlikowski & Yates, 1994). In fact, a living entity communicates with its living surroundings one way or another to survive – an infant cries to communicate with her/his parents; a student uses body-language to communicate with her/his peers in classroom; a teacher speaks to communicate with her/his students; an author writes to communicate with her/his readers; and a police officer uses a sign to communicate with traffic.

In each of these instances, a means is employed to share a piece of information and to deliver a message: an infant cries to request food; a student points at her/his head to show her/his understanding or lack-thereof; a teacher lectures to share her/his knowledge; an author uses words to share her/his experience; and a police officer raises a stop sign to order a driver to stop. Thus, communication is an intentional interaction between two living parties to share a concept.

Communication exchanges a piece of information between two living entities through a process: a living entity – i.e., a sender – decides to intentionally convey a piece of information – i.e., send – to another living entity – i.e., a receiver. As such, communication process takes place to deliver a message and to define a purpose.

(2.1) What Is Communication?

Communication refers to an exchange of information by use of a medium between, at the least, two living entities. In such a process, four (4) main activities occur:

a) Encode: a thought, a piece of information, or an idea is generated in mind of a living entity. Irrespective with how incomplete an idea is, how meaningful a piece of information is, or how unparalleled a thought is, its sender intends to share it with a receiver which is often another living entity. A sender is a living entity which initiates a communication process and is often held accountable for success or failure of a message: Did a shared piece of information deliver the intended message? Is this information communicating the message which the sender intended for the receiver to understand (Sanchez, 2008)? This piece of information or idea is encoded by a living entity – i.e., its sender – for presentation. In other words, information is prepared by its sender and encoded in some form. The encoding process may involve a language, a word, or a gesture to represent a concept – for example:

- i) A sender may encode an idea into form of a verbal – i.e., non-written – question;
- ii) A sender may encode a piece of information into form a written report; or
- iii) A sender may encode a thought into form of a visual signal.

It is important that a sender understands the communication from its receiver's point of view – does an encoded piece of information convey the intention of its sender?

b) Transmit: This piece of encoded information is intentionally conveyed to another living entity by use of a medium. A communication medium may be verbal, e.g., face-to-face conversation which often offers a quick impact; it can be visual, e.g., a light signal; it may be written; e.g., a technical memorandum which is intended to reach a group of recipients; or it will be a combination of these media. It is the purpose of communication which dictates the effectiveness of its medium (Sanchez, 2008). Therefore, it is important for a sender of a message to choose an

appropriate medium of communication to transfer an encoded piece of information to its intended recipient(s).

c) Decode: A living entity who receives this information needs to understand its content in order to react accordingly. A piece of information must be translated – i.e., decoded – to an understandable message by its receiver. In this step of a communication process a receiver decodes a message. A receiver is a living entity in one end of a communication process towards which a message is directed. A receiver plays an opposite role of a sender: decoding a message. A receiver interprets an encoded message which is encoded into a certain form by its sender and assigns it with a meaning.

d) Feedback: Once decoding was conducted and a message was understood, the receiver responds to it. Such a reaction is referred to as ‘feedback’ (Sanchez, 2008). Without feedback a sender will not be able to evaluate effectiveness of its message and to identify its barrier(s). A successful communication occurs when a receiver understands a message as intended by its sender.

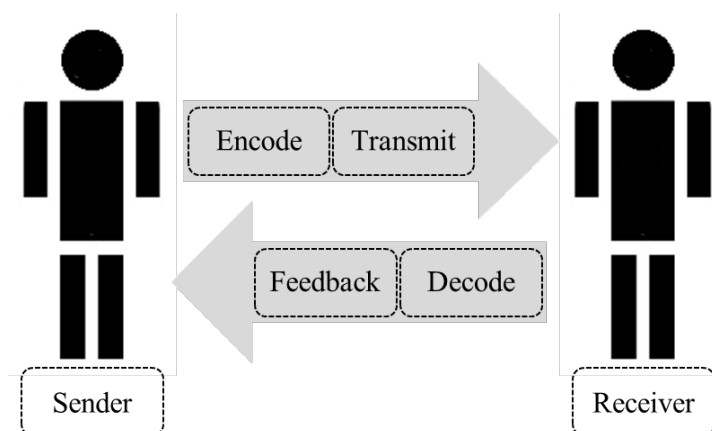


Figure 2.1– A Schematic Model of Communication; Adapted from Source: (Sanchez, 2008)

(2.2) What Is the Purpose of Communication?

Communication connects two or more living entities. Connection forms a structure among its counterparts and constitutes an organization (Schall, 1983). Within an organization communication functions as a source which is supposed to:

- i) exchange information between its participants;
- ii) inform its participants of an assignment to be accomplished – i.e., a '*what-to*'; and
- iii) explain to its recipient how a task should be performed – i.e., '*how-to*'.

A piece of information which is communicated will describe the purpose of communication. Therefore, in a communication process, the preparation of information content and its presentation is critical, given how sensitive the output of communication is to its content. This sensitivity comes from the fact that purpose of communication is to inform its recipient of '*what-to*' do and, in many cases, explain '*how-to*' do it.

As a piece of information reaches a person in a process of communication, an array of options on intention of its content is introduced to the receiver. Clarity or rather explicitness of this information of a form is a critical parameter in determining number of feasible options in the interpretation array. Obviously, more choices of interpretation generate a greater likelihood of misinterpretations and consequential errors. Conversely, a clear piece of information narrows down options in this array of interpretation to one, or otherwise a very few.

A piece of information has to be well defined so its receiver can easily understand it. A well-defined message tends to offer a better understanding of its content. Information should also be clear. A complete and perfect piece of information offers its receiver a better awareness of its

intended message and helps its receiver in process of decision-making. Receiver of an incomplete/imperfect piece of information is often challenged to decode it and seeks in its surroundings environment to fill in for missing information in order to make it meaningful and to understand it.

Communication process is supposed to share a common meaning between its participants. In management concept, exchange of desired information along with clear explanation is referred to as an effective communication. In other words, a piece of information in effective communication is received 'exactly' as it is intended to be. Therefore, not only communication but also an effective communication brings about a common understanding of a 'what-to' between its sender and its receiver.

Peter F. Drucker (2006) in his book, *The Effective Executive*, defines effectiveness as 'doing the right things'. In scope of this investigation, 'the right things' infer the intended thing that a person desires to communicate, which in exaggeration, may not necessarily be a right thing in accordance with known regulations. 'Doing the right things' in this thesis refers to successful delivery of an intended outcome.

In conclusion, it is a 'precise and crisp', or in other word an explicit, piece of information which makes or breaks an effective communication (Management Study Guide, 2008). Explicit communication often eliminates chances of misinterpretation and its consequential errors while an implicit communication creates misunderstandings and conflicts.

(2.3) Communication in a Construction Project

Communication in an organization delivers an instruction to influence actions of its receiver (Dainty, Moore, & Murray, 2006). In other words, communication in an organization determines who will do what (Orlikowski & Yates, 1994).

A construction project, of any size, is a temporary project-based organization and, therefore, is not excluded from the Schall's (1983) principle that communication defines an organization. This temporary organization is structured to deliver a unique product (Project Management Institute, 2000).

In a construction project, information is often in form of an instruction and is exchanged to direct its participant – e.g., a skilled trade worker – as to its assignment – a 'what-to'. This assignment, then, will deliver an outcome. In such a process, when the instruction is completely understood, the delivered outcome will represent the intended result. Otherwise, an error occurs and the delivered product deviates from its expectations.

Errors in construction projects are often defined as failure in doing a designated task (Hagen & Mays, 1981); an occasion in which a planned activity fails to achieve its desired outcome (Wantanakorn, Mawdesley, & Askew, 1999); or an outcome which deviates from an acceptable exactness (Nowark & Carr, 1985). In turn, an error is a symptom for misunderstanding; and misunderstanding itself is a common output of a communication process which is interrupted with a barrier. In other words, a communication barrier is an obstacle arises in process of a communication and impacts its effectiveness. A barrier interferes with a communication process and distorts a message.

A communication barrier can be identified within two main categories:

- i) Information quality: an instruction is of such poor quality that has no clear objective. This often develops uncertainty as instruction does not seem appropriate to a situation; and
- ii) Information understandability: an instruction is not easily understandable as it is not appropriately conveyed.

Quality and understandability are foundational elements which make or break an effective communication process.

A variety of parameters may create an obstacle in a communication process (Project Management Institute, 2000; Dainty, Moore, & Murray, 2006) and result in an ineffective communication:

- a) an unorganized thought/an unclear objective does not offer a clear intention (information quality) and does lead to an ineffective communication. A sender should transfer clear information to the receiver for an effective communication;
- b) a wrongly interpreted piece of information may lead to a misunderstanding (information understandability) – that is, a sender and a receiver attribute different interpretations to a piece of information;
- c) an external cause may develop a faulty communication process, distort an instruction, and create a misunderstanding. An inappropriate medium of communication, a noisy environment, a distracting phenomenon, a long distance, and such attribute in miscommunication and often bring about misunderstanding; and
- d) an internal cause such as cultural level, mood, and motivation may distort intention of a piece of information and create misinterpretation.

These barriers of communication characterize a faulty exchange of information, challenge effectiveness of a communication process, and lead to misinterpretation of information by its receiver (Wantanakorn, Mawdesley, & Askew, 1999; Dainty, Moore, & Murray, 2006).

A construction project often experiences these barriers in its communication processes. For example, objective of a project is not clear as project participants receive incomplete information; or information is wrongly interpreted as participants of a project may have different professional background; or a piece of information is misunderstood as there is considerable distance between its participants and a communication chain transmit the information between project participants.

Shortage of information in a construction project leads to delivery of an undesirable outcome (Shohet & Frydman, 2003). An instruction needs to be explicit, should deliver sufficient knowledge on a ‘what-to’, and is supposed to create common understanding about a desired outcome – or rather a defined goal. Communication of an instruction which lacks its required quantity in a construction project impacts delivery of a task.

A communication process is composed of four (4) main activities: encoding, transmission, decoding, and feedback. In a construction project, encoding a piece of information into a form of message is critical as the literature has reported effective encoding of information to be a major problem. For example, construction drawing(s), in which encoded message is in written form, are often incomplete. Construction documents also represent instructions which are often found to be in conflict with one another (Dainty, Moore, & Murray, 2006).

A communication process is successful when a receiver of a message understands it exactly as its sender intended. The extent to which this exactness takes place is a function of many variables residing with both the sender and the receiver. Knowledge, experience, skill, and perception are a few of these characteristics (Sanchez, 2008). Each of these parameters influences in one way or another, the effectiveness of communication and also impacts the interpretation of a transmitted message. This thesis acknowledges that effectiveness of a communication is not solely a function of the effectiveness by which a piece of information is prepared (i.e., encoded) for transmission to the sender. However, to have a reasonable scope of focus, this research will be investigating what the receiver of the communication does when he/she faced with a piece of information – perfect or imperfect – and consequently outcome of such communication process.

An ineffective communication process develops misunderstanding as the message carries uncertainty with itself. Thus, the receiver of such an encoded piece of information is not certain on its objective and the intended ‘what-to’ which the communicator intended to deliver. This uncertainty represents an obstacle preventing the receiver of the information from comprehending ‘what-to’ do and making the next decisions.

The ability of the receiver to decode the information will only improve by requesting more information from the source. The receiver may choose to ‘fill in the gaps’ which brings about misinterpretation of a message and results in a form of waste as the intended thing, which is supposedly ‘the right thing’, is not delivered. Clearly, an effective communication in a construction project promises the highest likelihood of execution success.

The literature on construction project communication, its process, and its effectiveness often investigates the outcomes of inappropriate interpretation of an instruction and implementation of

an inadequate decision; that is: what happens if an inappropriate instruction is interpreted [the receiver decided to fill the missing information] and an inadequate decision is accordingly made? In other words, the focus of the literature is on what happens if a wrong 'what-to' do is interpreted and consequently implemented?

Parker (1980) also presents quality of communication as an obstacle in productivity of (a task) in a construction project. Parker also states that failing to provide sufficient instruction in a timely manner for even a simple construction activity can impact schedule of task delivery and can hinder overall project productivity.

Dozzi and Abourizk (1993) state that clear explanation of an assignment contributes to delivery of a successful construction project. It is important that a worker exactly knows a task which he/she is expected to accomplish. Lobel (2008) mentions that feasibility of a construction project can be influenced by misinterpretation of information. It is adequateness of information and, in turn, effectiveness of decision-making which contribute to success of a construction project (Chan, Scott, & Chan, 2004).

Majid and McCaffer (1998) and Al-Khalil and Al-Ghafly (1999) introduce poor communication among main causes of a non-excusable delay in schedule performance of a construction project. Hoezan, Reymen, and Dewulf (2006) also mention waste-of-time as one of major consequences of poor communication in a construction project.

Liberda, Runwanpura, and Jergeas (2003) also identifies non-availability of information as one of the most critical parameters and inadequacy of communication as of one prioritized factors which influence productivity of a construction project.

Hoezan, Reymen, and Dewulf (2006) explain that efficiency and effectiveness of a construction project – i.e., doing the right things and doing things right, respectively – strongly depend on quality of communication. Better communication in a construction project reduces frequency of its failure and leads to a better decision-making.

Yang, Ahuja, and Shankar (2007) concluded that effective communication to be crucial for successful delivery of a construction project. Gunhan, Senol, and Dogan (2012) also identify effective communication as a critical element in delivery of a successful construction project. This study stated that performance of a construction project is greatly affected by ineffectiveness of communication.

Memon, Rahman, and Aziz (2012) find that completeness of information and clearness of instruction which a skilled trade worker receives among measures which improve schedule and cost performances of a construction project.

The studies cited agree that broken communication in a construction project often occurs in the form of a written instruction (e.g., a set of construction drawings) or a verbal instruction (e.g., face-to-face discussion). Regardless of its formal or informal manner of presentation, a written or a verbal instruction is expected to be complete and clear to convey its intended message.

(2.4) Cue In Communication

So far, communication processes have been discussed with respect to its definition and constitutional components. The discussion has revealed two characteristics of an instruction, namely, quality and understandability – as parameters which influence effectiveness of a communication process the most. The manner with which communication has been addressed in construction literature has also been explored.

This section attempts to address how ineffectiveness of a communication process impacts a construction operation execution as this level has not been discussed in prior research and is a worthwhile effort.

As mentioned earlier, effective communication eliminates inexactness and offers an explicit instruction. Such explicitness serves as a signal and will result in performing the-right-thing. Signal is a solid statement which conveys an absolutely understandable instruction.

An ineffective communication, on the other hand, offers ambiguity to its receiver – that is, an inexactness of its meaning. Such inexactness can provide more than one interpretations for an instruction. The receiver of this message therefore has to decide which interpretation is the intention of this implicit message – or its sender – and will result in the-right-thing. Such interpretation and its consequent decision-making take place based on a non-stated cue.

An implicit instruction along with an environment, where it is expected to be implemented, forms a cue and, in turn, imposes a cue interpretation process. A cue may be defined as a ‘physical hint’ or a ‘verbal hint’ which is an existing element in an environment and is sought to guide the executor of a task to act in a particular circumstance. Therefore, it is important to understand a cue as a hint which is not generated by sender of an instruction. In other words, a cue is a ‘physical hint which voluntarily offers complementary information and is readily available to be understood. It should be understood that no explanatory enough cue exists to overcome incompleteness/imperfectness of an instruction. An instruction is intentionally delivered to a receiver and a cue is identified by user of an instruction.

A signal is essentially a perfect cue, as there is no need to engage in any interpretation or guess work. Therefore, a cue is an imperfect signal. Acting upon a cue often creates waste and re-work. It is this waste and re-work that this research is attempting to quantify in a conceptual way using Agent Based Modeling.

The situation in which an instruction is incomplete, is unclear, or is, simultaneously incomplete and unclear, and a worker decides to employ the surroundings physical cue to complete the incomplete information can be regarded as a '*Make-Do*' situation. This is a situation in which an activity is started without its necessary input (Koskela, 2004). Since making-do has been claimed as the eighth category of waste in a process (Koskela, 2004), decision-making on basis of an available cue may introduce waste into construction process.

Other consequential waste can be a re-work. An inappropriate interpretation of an instruction and making a decision based on an available cue will result in an undesired outcome – i.e., wrong or incomplete – and will require a re-work.

Delay may also be another consequential waste within such a process. When the non-optimal cue is employed in decision-making and an undesired outcome is delivered, delay can be experienced either due to unavailability of required work to the successor activity or due to some schedule slippage as a result of re-work.

Incompleteness of an instruction imposes decision-making according to surrounding cue. Such a process brings about confusion and eliminates common understanding of a message between its sender and its receiver.

It needs to be mentioned that an instruction may lack a piece of its required information due to a variety of reasons – e.g., a communication process which is interrupted by a barrier; a work situation which has changed due to its nature; a construction skilled trade that does not have the required knowledge level, and such. This is not the topic of this investigation.

In a construction project, a user of instruction – e.g., a skilled trade worker – similar to any recipient of information – often accepts it as is and consequently implements it in the form it was transmitted. In other words, a decision about ‘what-to do’ is made on basis of prior determined planning and a message that conveys this instruction. If an instruction is not effectively communicated, is not well defined, or is not understandable, then the worker, or entire crew, will either decide to request more information or look for a cue to complete the missing information. Although it happens frequently there is no research that explains why a worker, or a crew, would seek to find a cue.

(2.5) Why Simulation is Chosen

Studying human behavior can be a challenging task. Depending on its area of investigation, such study may be financially inefficient, timely impossible, or physically infeasible – let alone the ethical issues of such an approach. Decision-making is an example of human behavior. Such an interaction of a human with its surroundings is almost physically infeasible to capture as several parameters consciously/unconsciously impact the behavior and conclude in a decision. For that matter, it is almost impossible to concentrate on a specific parameter while several ones are not controllable. In addition, repetition can always be an issue in experimentation of human behavior as it is almost infeasible to observe two identical humans interact with a unique environment. Apart from feasibility of studying human behavior, cost of such an experiment is sometimes

inefficient and promises no motivating return for investment. To overcome some of these challenges, computer simulation provides the benefits to reproduce behavior of a human – in this case decision-making.

In order to investigate the impact of imperfect information contained in a directive to accomplish an assignment, it is critical to employ a system which is influenced in a similar manner by a parameter as it recurs. Construction projects are almost always unique – it seems almost impossible to compare two projects which are exactly identical. Nor is it imaginable to employ a skilled trade worker whose knowledge of a discipline from past experiences does not impact his / her behavior in a reoccurring decision-making.

Therefore, a simulation can properly and closely model real life behaviors. Such simulation may be utilized in evaluating performance as alternative plans are introduced.

(2.5.1) What is Agent-Based Modeling – ABM?

Among computer simulation methodologies and specifically in *Object-Oriented Programming* (OOP), *Agent-Based Modeling*, also known as ABM, is a relatively a modern approach. In this simulating practice, a phenomenon is modeled as a dynamic system with a collection of interacting agents (Castiglione, 2006). In ABM computer modeling a group of ‘autonomous’ entities simulates a real-life occurrence. Each entity, which is known as an ‘*agent*’, in this assembly is able to assess its situation at a point in time and make decision in accordance with a set of rules (Sawhney, Walsh, & Mulky, 2003). Such an underlying structure enables an ABM to exhibit ‘complex behavior’ of an organization it represents and to reveal ‘information about the dynamics’ of such organization (Bonabeau, 2002).

(2.5.2) Why is Agent-Based Modeling Chosen?

Agent-Based Modeling (ABM) is best known for its three (3) major advantages (Bonabeau, 2002) over other computer simulation techniques: a) An ABM can emulate an emerging phenomenon – an occurrence which may not easily be predictable and understood; b) An ABM offers a natural description for a system it represents – a depiction of activities which happen within an organization. In other words, defining a structure from the viewpoint of its constituent activities offers a more natural description; and c) An ABM provides a flexible structure to accommodate complexity of characteristics of its elements.

In a construction project process, each participant is influenced by his/her surrounding environment. This very fact imposes interaction between participants of compatible/incompatible characteristics and in turn introduces a context of great involvedness. Such interaction and degree of its complexity bring about an outcome and may impact, as a consequence, an entire process – an event which often is difficult to predict. In order to understand and analyze such a complicated process, observing behavior of its contributors uncovers the events which actually happen and assists in rationalization of results.

Thus, an ABM technique promises a suitable fit to emulate a construction project environment.

(2.6) Chapter Summary

In Chapter 2 – Background ‘communication’ in its general course is defined and different attributes of a communication process are introduced. These attributes of a communication process were next broken down into the concept of ‘Effective Communication’. Then, a barrier

in a communication process was defined and its characteristics were identified in a communication process.

There are several parameters which disturb the process of effective communication. These parameters define barriers of effective communication. The intention of this thesis is to investigate impacts of perfect against an imperfect instruction on the execution of construction work using a hypothetical and simulated ABM construction environment. In four (4) steps of communication process, it concentrates only on an encoded piece of information to introduce its impacts of delivery of a message. Therefore, communication barriers in this thesis are categorized into two main categories: i) information quality; and ii) information understandability.

Chapter two (2) revealed that a broken communication will not deliver an intended message to its receiver and consequently forces its user (i.e., a message recipient) to either seek further clarification from the source of the communication or to utilize its surrounding's available cues to make sense of an incomplete instruction. If the choice is to use cues, this is akin to a making-do situation when at least one necessary requirement for successful completion of an activity is missing – imperfect information.

There is no study which presents how imperfect instruction impacts the execution of a task. Literature has often pointed out that incompleteness of information and ineffectiveness of a communication are amongst the variables which influence outcomes of a construction process and a project as a whole. In order to understand such an impact, a computer simulation technique is utilized and an abstract ABM is designed to study the process.

(3.0) Chapter Three – Method

This explanatory and deductive investigation was divided into five (5) phases, as Figure 3.1 illustrates, to move towards its goal and satisfy set objectives.

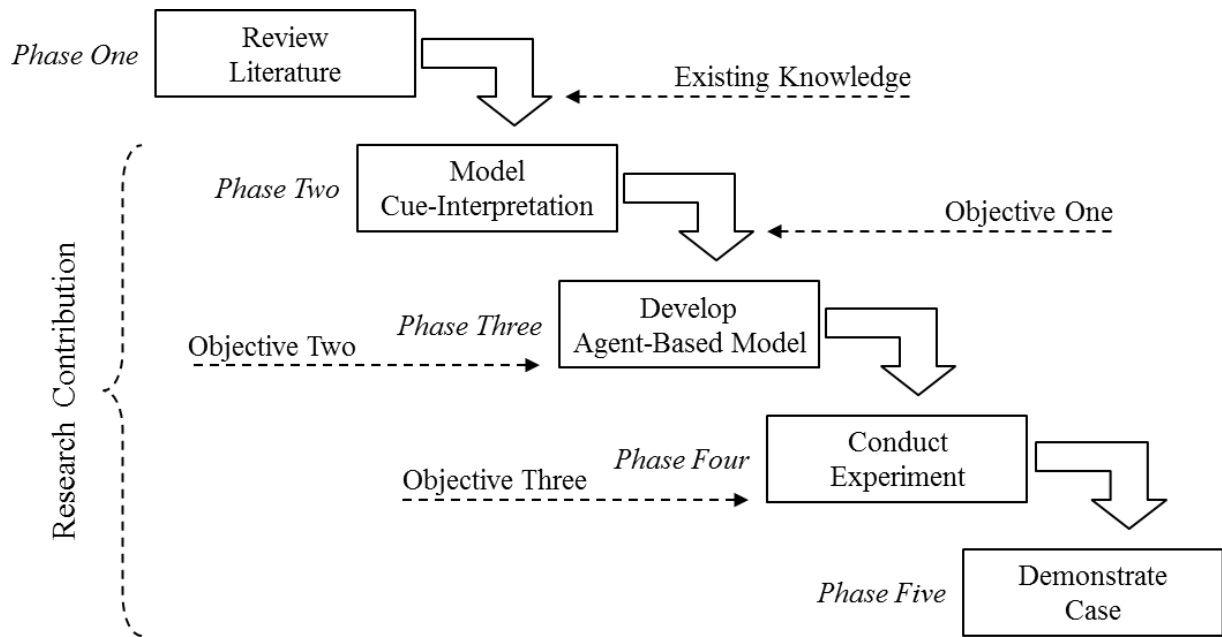


Figure 3.1 – Investigation Framework

(3.1) Investigation Approach

In exploration for answer to the problem statement, an Agent-Based Model, also known as ABM, was proposed. ABM is employed in order to realize, by means of simulation, some predictions of a real-life situation as to how a user responds to a communication process, taking into consideration amount of information transferred.

In order to provide a realistic environment for the investigation, the proposed model experienced several advancements from its initial form over the course of this investigation. Nevertheless, in all versions of simulations, an agent interacts with its surrounding environment as its user: in a

desired situation, an environment ‘S’ – which symbolizes presence of a sign – directs its user towards a predetermined destination with means of a ‘sign’. A sign is meant to represent a clear demonstration of an anticipated action. In a less preferred circumstance, the environment ‘C’ – which corresponds to existence of a cue – is set to force the same user to comprehend a ‘cue’, representing an implied illustration of the same anticipated action and exercise decision-making.

(3.2) Model Description

(3.2.1) AgentSheets Simulation Tool

In its stage of development, the simulation was developed in ‘AgentSheets’, an educational Java-based simulation tool which offers visual programming with its built-in drag-and-drop language (Wikipedia, 2012). This model introduces its agents as an environment and a user – the environment pretends to pose a ‘construction job site’ and the user considers itself as a ‘skilled trade worker’.

The job site is in possession of specific unambiguous indicators. A ‘white-color square’ offers a moving ‘path’. A moving path itself is considered a job site – therefore a job site is a collection of several sub job sites which are referred to as moving path. There are locations where a moving path is blocked by a ‘black- & white-color bar’ to represent presence of a ‘wall’. Also, there are two pre-arranged locations: a start point and a finish point which are positioned, respectively, in local South and local North of directions. In such a maze, a ‘black-color arrow’ in South of direction represents a predetermined start point, and a ‘black-color shelter’ characterizes an arranged finish point in North direction of a job site. The skilled trade worker is supposed to leave the start point and land in the finish point. Table 3.1 summarizes aforementioned indicators.

Table 3.1 – Description for Common Indicators of a Job Site

Indicator	Description
White square	Pathway
Black & white bar	Wall [i.e., Stop moving; it is blocked!]
Black arrow	Start point
Black shelter	Finish point [i.e., Stop moving; it is a destination!]

In a job site developed in AgentSheets, a ‘sign’ and a ‘cue’ have different manifestation. That is, besides the start point and finish point, a ‘black-color diamond’ represents an explicit instruction and provides a skilled trade worker (i.e., its user) with a solid piece of information as to the direction towards the desired destination. Properties of each location, in the meantime, will offer a skilled trade worker a set of implicit directives about the direction of movement. In other words, upon a movement, mathematical coordinates for position of a skilled trade worker – which is evaluated in accordance with a predetermined destination – and characteristics of its neighboring area forces the skilled trade worker to interact with cues and to exercise decision-making in order to find a pathway. This exercise continues unless presence of a sign instructs it otherwise.

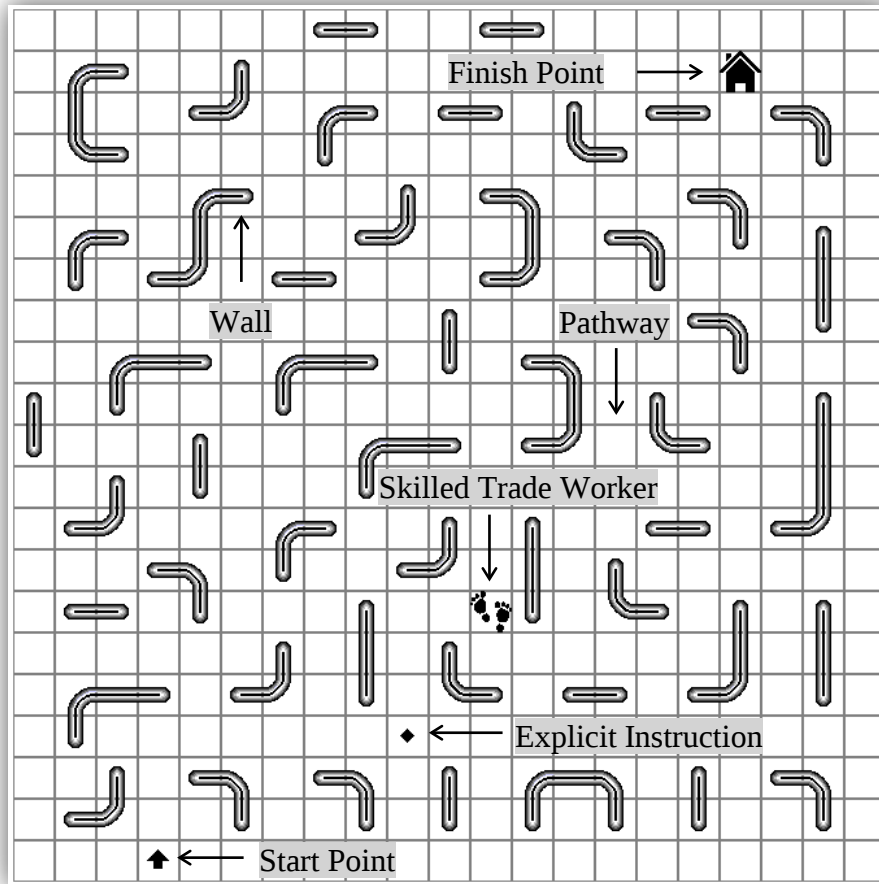


Figure 3.2 – Representation of a Job Site and its Communication Means (AgentSheets)

In this simulation model, an agent, i.e., a skilled trade worker, is introduced to two environment S and environment C, where, respectively, a sign is designed to explicitly instruct its user and a cue will forces the same user to exercise decision-making. As is shown in Figure 3.2, a ‘pair of foot-print’ symbolizes a skilled trade worker which is required to move in the job site and travel from a start point to a finish point.

If explicitness of an instruction is scaled on a continuum, opposite ends of such continuum are supposed to represent explicitness and implicitness. Therefore, as approaching one end of

continuum, degree of explicitness decreases adversely. In order to simulate such analogy, clarity of an instruction, which is communicated between an environment and its user, was introduced in three main scenarios: a) an explicitly-instructed environment S (one end of continuum); b) an implicitly-instructed environment C (the opposite end of continuum); and c) an environment C with varying level of explicitness (the range between two end points of the continuum).

Logic of a movement for an agent as a representative of a skilled trade worker in this simulation has been based on three statements:

- Location (sub job site) an agent *SHOULD* visit,
- Location (sub job site) an agent *CAN* visit, and
- Location (sub job site) an agent *WILL* visit.

The skilled trade worker in this simulation is assigned with a task of traveling from a predetermined start point towards a designated destination. In order to relocate, an agent considers these three main statements and reacts accordingly as its surrounding environment permits.

While developing this simulation model in AgentSheets, the environment and its user were, for solely purpose of simplicity, imposed to comply with several regulations. In brief, it was ruled that:

- a) In environment S, a skilled trade worker only interacts with an explicit, i.e., a perfect, instruction.
- b) In environment C, a skilled trade worker of the same knowledge level and understanding interacts with implicit, i.e., incomplete instruction, to exercise decision-making.

- c) In either environment S or environment C, the skilled trade worker remembers a neighborhood it visited and does not consider it as an available sub job site. A visited neighborhood will become an available location to accommodate a movement only if an agent faces a dead-end.

While living in job site of environment S, a skilled trade worker will only follow the ‘black-color diamond’ directives and will reach its destination to satisfy its assigned task. In this very scenario, locations of ‘SHOULD’- and ‘WILL’-visit exactly match as explicit instruction is present: a skilled trade worker *will* relocate to its neighborhood which *should* be visited to where an explicit instruction directs it.

In job site of environment C with either absolute implicitness, i.e., no instruction, or where degree of explicitness decreases, however, the same skilled trade worker behaves differently to reach its destination. Within such environments, ‘SHOULD’- and ‘WILL’-visit neighborhood locations may not coincide since ‘CAN’-visit neighborhood locations rules ‘WILL’-visit neighborhood. That is, an agent prior to each attempt for relocation recognizes its position and identifies its corresponding coordinates, considering the mathematical location of the finish point, to obtain information and to decide upon direction of next movement. In other words, a skilled trade worker constantly examines its coordinates and evaluates its distance from the predetermined destination along with two directions of a plane so an appropriate decision is made. In a mathematical term, and as illustrated in Figure 3.3, such condition for decision-making will translate as:

- Identify mathematical coordinates for location of a skilled trade worker along both parallel and perpendicular directions of a two-dimensional plane and compare it with the coordinates for location of the finish point in the same two-dimensional plane.

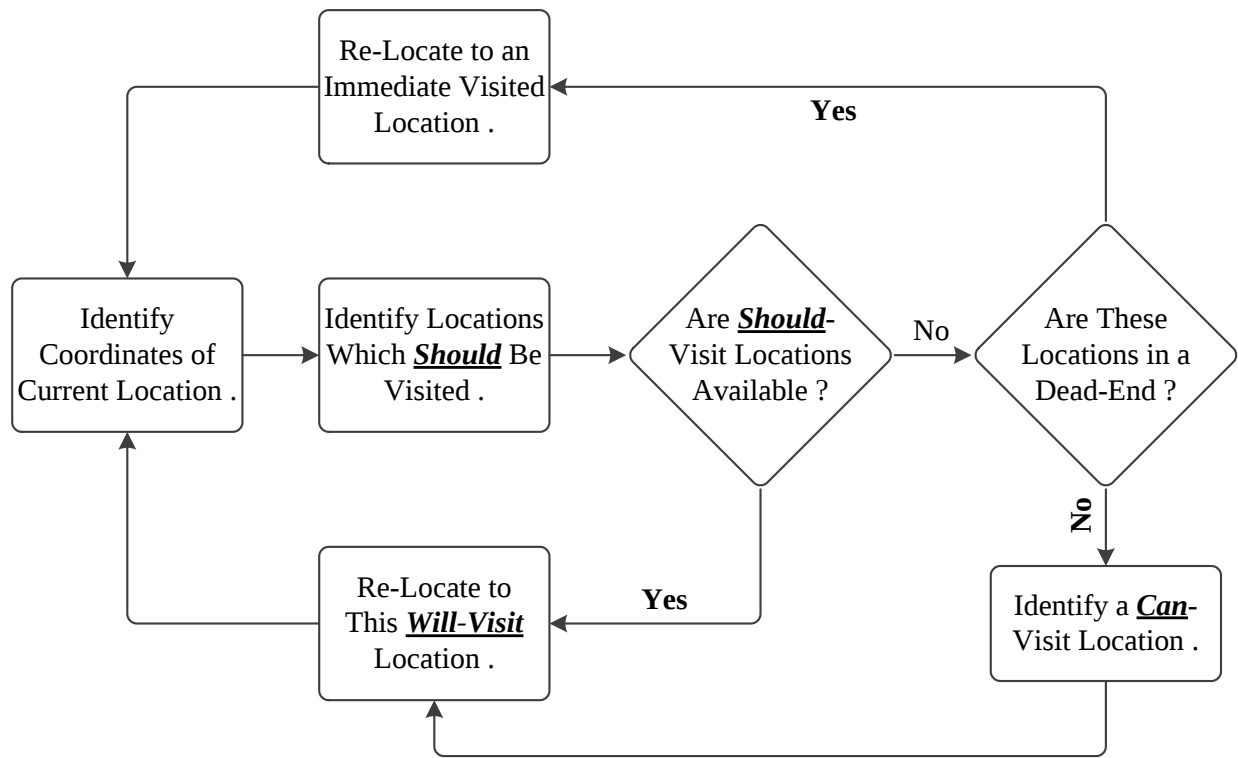


Figure 3.3 – Diagram of Agent Decision-Making Process

As such an evaluation is performed an immediate location which *should* be visited is identified and skilled trade worker knows its next move to accomplish its assignment. Feasibility of this identified direction of movement, however, is a dependent of availability of neighborhood locations in north, east, south, or west of direction. In fact, an agent *will* often visit a neighborhood it *can* visit – a visit which may not at all accord with one that *should* be made. An instance of this scenario will be a situation where a skilled trade worker locates itself in coordinates which are identified somewhere below coordinates of finish point along both axes of

two-dimensional plane where it is positioned – this very fact reveals a neighborhood location to where skilled trade worker *should* relocate: i.e., north and east of its local position. Possibility of this *should* is realized upon existence of a sub job site in north or east of directions, where the skilled trade worker *can* visit. If feasibility of a movement proved positive, then an agent decides, with equal probability for available choices, upon a sub job site to where it *will* move next. In a situation where execution of *should* is not a possibility, a skilled trade *will* accomplish what it *can*.

Assessment of distance relative to finish point is performed by a skilled trade worker until it recognizes a black-color diamond which is supposed to instruct its user towards a specific direction. Such occurrence is prevalent over the decision which is made by a skilled trade.

It is important to note that the logical basis on which this simulation is designed assumes no learning ability for an agent. This assumption will fairly simulate an agent which is exposed to an environment for the first time. Equal opportunity of choice also masks the learning curve and in turn will offer a fair stochastically decision upon availability of a location in the job site where requirements of movement is accommodated. At the same time, the existence of an obstacle, i.e., wall and job site boundary, in any of four directions eliminates a choice and suggests less ambiguous instruction. Limitation of choices, however, does not necessarily lead to a correct decision.

In summary, the logic which governs decision-making ability of a skilled trade prioritizes option of coordinates over choice of job site availability. That is, coordinates which directs a user closer to its destination always wins the encounter when a neighborhood has the same equal

opportunity. This condition will offer limited randomness in choice of direction as a part of the decision that is dictated by the coordinates in which an agent is located.

(3.3) Chapter Summary

In the course of this investigation, Agent-Based Modeling (ABM) was employed for realization of proof for the investigation question. AgentSheets, an educational Java-based simulation tool, was utilized for simulation. AgentSheets offers visual programming with built-in drag-and-drop language. In order to observe behavior of an entity upon presentation of an instruction, the simulation is designed for two agents which interact with one another.

One agent which characterizes a skilled trade worker is introduced to another agent representing the construction job site environment. The environment is in possession of other agents which are representations of different directives. Response of a skilled trade to different situations is observed: a set of explicit instructions also known as signals, a series of implicit directives also known as cues, and a combined collection of explicit and implicit instructions.

This simulation is conducted for a number of repetitions and performance measures were collected based on the decision-making results of the agent representing the skilled trade worker. The number of moves a skilled trade worker accomplishes towards approaching its predetermined destination is considered as its effort for completion of its committed assignment and is evaluated for assessment of effectiveness of an instruction, and the overall execution of a task.

(4.0) Chapter Four – Results and Analysis

(4.1) Computational Experimentation

As was mentioned in the earlier chapter, an agent which is representing a skilled trade worker is introduced to three (3) main scenarios where its behavior is evaluated – a) The agent lives in an environment S, as in Figure 4.1, which is extensively instructed and sufficient number of signs guides it to a predetermined destination. An environment S is considered to present an optimal job site where a skilled trade worker performs the most effectively – i.e., 100% instruction and the least number of moves between start point and finish point. A job site of an environment S is identified as reference case. Movement history of an identical agent which lives in a different environment, thus, will be evaluated on basis of number of steps through which it can reach finish point in the reference case – i.e., environment S.

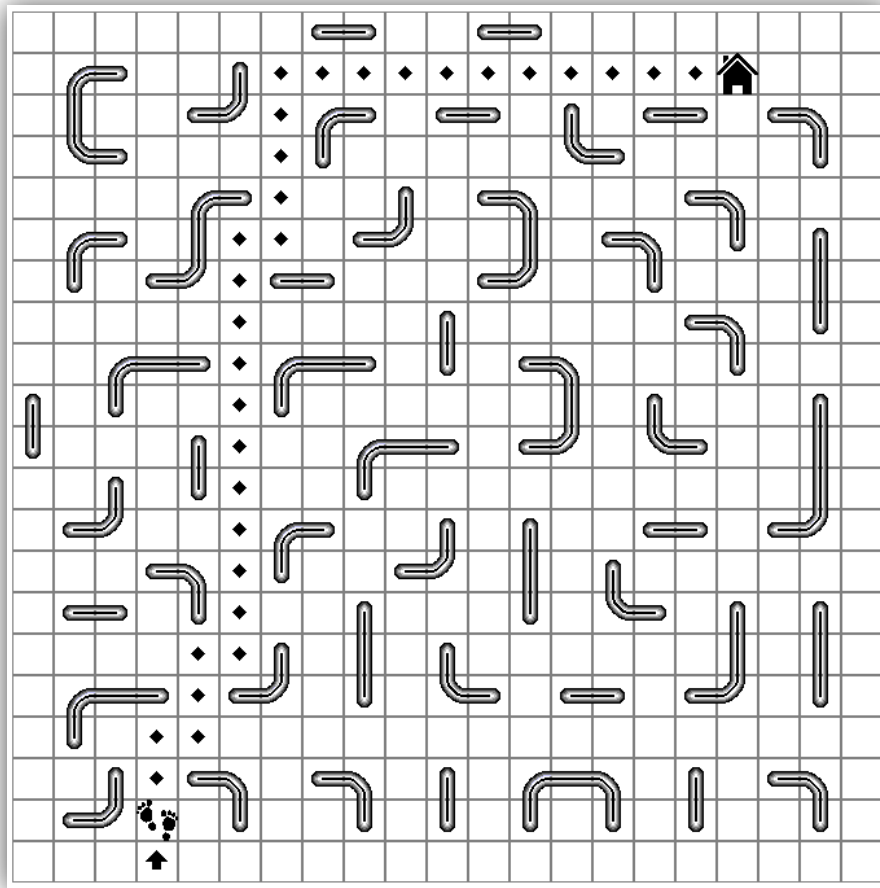


Figure 4.1 – Representation of an Environment A_1 with Instruction (i.e., Signal)

One may legitimately wonder on what basis thirty one (31) steps represent the least number of moves between start point and the destination. In order to verify this statement, an agent, i.e., a skilled trade worker, was introduced to environment V to characterize a simple job site.

This environment V is an identical duplicate of environment C if blocking ‘black- & white-color bar’ which represents a wall is omitted. In other words, job site V is a job site C with no walls – and for that matter a job site S with no walls and 0% instruction. Such an environment comfortably serves to verify the least number of times a skilled trade worker will have to relocate

in order to travel from start point to finish point since i) there is no obstacle to eliminate possibility of a movement in a direction, and ii) there exists no instruction to over-rule a decision made by an agent. Environment V, which is presented in Figure 4.2, proves a maximum and a minimum number of thirty one (31) movements between start point and destination.

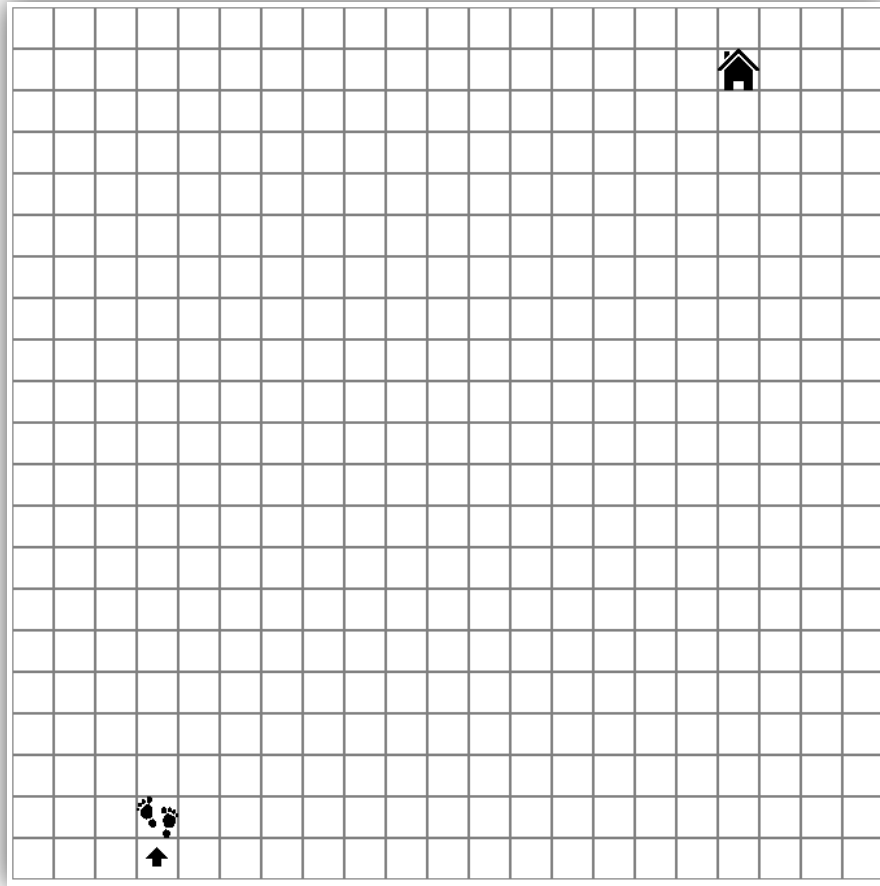


Figure 4.2 – Representation of Environment V (i.e., Verification)

b) The agent lives in an environment, as in Figure 4.3, where no instruction (0% of optimal case) is present. This job site offers its user, i.e., a skilled trade worker, no instructions and an agent is supposed to solely rely on its knowledge and surrounding cue in order to complete its assignment and reach the predetermined destination. Knowledge for an agent, in process of this

investigation, is defined as recognition of two-dimensional coordinates in a location, identification of an obstacle, and path- (way-) finding.

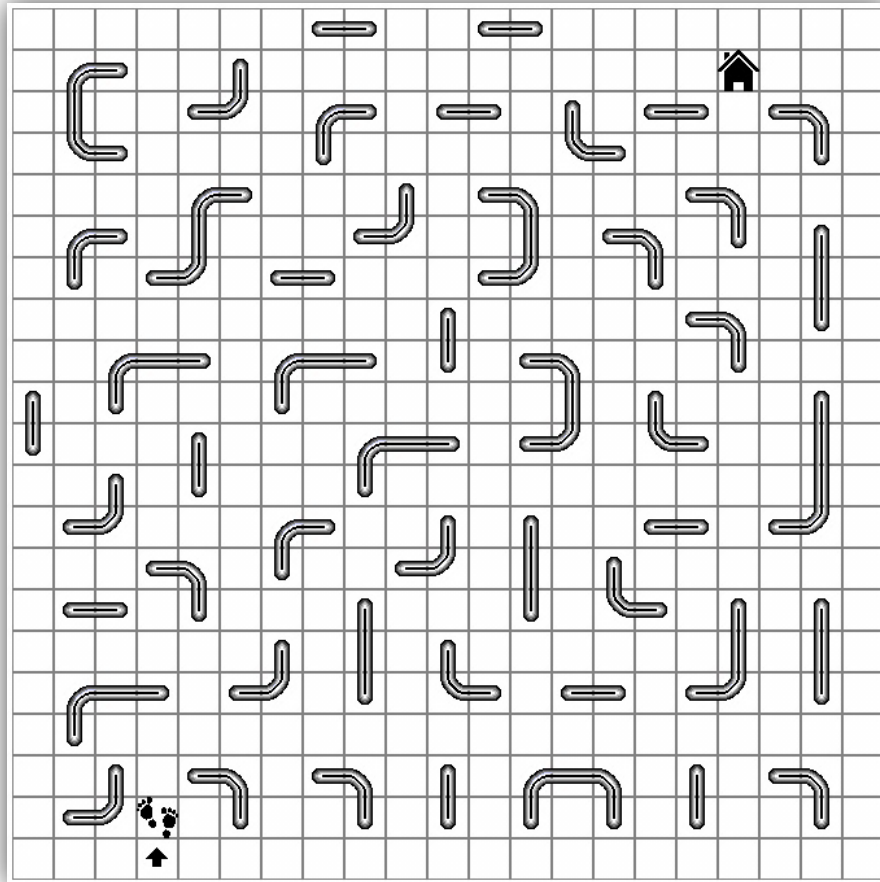


Figure 4.3 – Representation of Environment A_1 without Instruction (i.e., Cue)

c) The agent lives in an environment which carries incomplete (a percentage of optimal) instructions within implicitness-explicitness continuum. Such an environment is designed to forces its user to exercise decision-making by offering insufficient instructions within a range of minimum 10% and maximum 90% of datum with a 10% interval. Improvement in performance effectiveness of a skilled trade worker is assessed through comparison of its movement history

against the optimal situation as instructions decreases in quantity and implicitness increases in magnitude.

(4.2) Simulation Result

Between eleven (11) job sites in which amount of provided instructions ranges within 0% and 100% – environment C of solo cues and S of solo signs, respectively – a total number of five hundred and one (501) repetitions were observed for a unique layout:

- a) In environment C, an agent repeats its task fifty (50) times from start to finish.
- b) In each environment which is defined within two environments C and S, an agent repeats its task fifty (50) times. These nine (9) environments of 10% to 90% instructions sum to four hundred and fifty (450) replicates.
- c) In environment S, an agent repeats its task one (1) time from start to finish. Note that environment S illustrates an ideal circumstance and is extensively instructed in order to direct its agent carefully to a determined destination. As such a design promises to eliminate unplanned activities, an agent constantly performs optimally and its movement history is a persistent thirty-one (31) step. In summary, it is a deterministic model and will always result in an identical movement history.

A total number of fifty (50) repetitions are assumed a sufficiently large sample size to generalize behavior of an agent against presence of different level of instruction. This sample size of fifty (50) repetitions is supposedly large enough to balance existence of extreme abnormalities, if any, and offer an enough concentration of data around its mean (expected) value. Samples of small sizes often carry members of a greater variation which consequently induces a higher probability

for existence of unusual characteristics. In other words, observation of samples with fewer members is often an inference. Nevertheless, determination of sample size is not a simple task and is dependent on its corresponding experimentation.

In this investigation, an agent is initially introduced to an extensively instructed environment A_1 (i.e., a_A_1_100) which was described earlier in this chapter as ‘scenario a’ and is demonstrated in

Figure 4.1. Upon completion of its task, which is defined as reaching a predetermined destination for a total of fifty (50) repetitions, this agent will now be hosted by an environment of identical layout which randomly losses ten (10) percent of instruction offered in the previous one – that is, presence of ninety (90) percent through ten (10) percent instruction. A summary of these repetitions are reported in Table 4.1.

Note that each experiment within an environment is uniquely labeled in order of its characteristics: a scenario on basis of which an agent’s behavior is evaluated, layout of an environment which is introduced to an agent, experiment identification, an indicator for level of instruction which is offered by an environment within a particular scenario, and repetition number for each level of instruction. Therefore, a generic identity for an experiment can read as ‘*Scenario_Environment_Identification_Percent Instruction_ Replicate*’. An instance will be an experiment ‘c_A_2_30_45’ which refers to the forty fifth (45th) repetition for the environment A_2 with presence of thirty (30) percent instruction as a part of scenario c (i.e., Cue).

Table 4.1– Summary of Outcomes for Environment A_1

Experiment Identification	Instruction Level (%)	Number of Repetitions	Movement History (Steps)		
			Minimum	<i>Average</i>	Maximum
b_A_1_0	0	50	31	36	53
c_A_1_10	10	50	31	35	47
c_A_1_20	20	50	31	36	49
c_A_1_30	30	50	31	35	51
c_A_1_40	40	50	31	33	49
c_A_1_50	50	50	31	37	51
c_A_1_60	60	50	31	37	59
c_A_1_70	70	50	31	31	41
c_A_1_80	80	50	31	31	33
c_A_1_90	90	50	31	32	43
a_A_1_100	100	1	31	31	31

Outcomes of initial experiment of five hundred and one (501) repetitions promise no conclusion which will agree with correlation of instruction and effectiveness in this investigation – that is, a task is accomplished more effectively upon presence of more instruction. On basis of reported information in Table 4.1 , if no directive exists in environment A_1 (i.e., b_A_1_0), an agent moves thirty six (36) steps on average to travel between start and finish locations. Since optimum number of relocations is thirty one (31) steps, it will be rational to suggest existence of a general correlation among performance effectiveness and instruction as presented in Figure 4.4.

It is critical to understand that presentation of suggested correlation between ‘instruction’ and ‘effectiveness’ with a continuous line in this investigation does not represent dependability of performance of an agent from an experiment to another. It, however, is supposed to manifest a

trend for performance while an environment offers instruction in an increasing regimen. In fact, no-learning assumption itself, on basis of which behavior of an agent is designed, eliminates dependent performance for an agent among several repetitions of a single experiment, let alone dependency from one experiment to another. In other words, such an assumption simply claims an agent with no ability to remember of a relocation choice, either correct or incorrect.

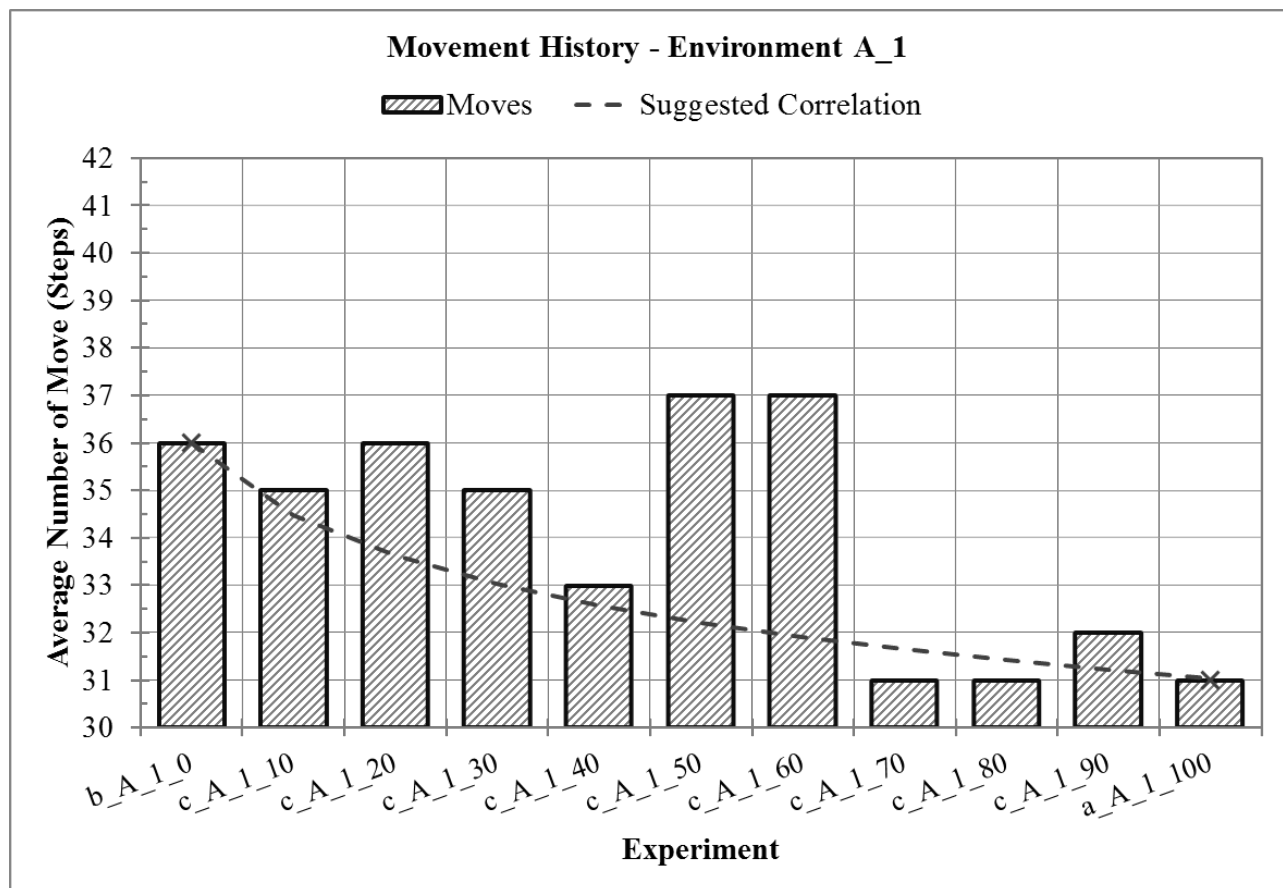


Figure 4.4 – Suggested Correlation amongst Performance Effectiveness and Instruction – Environment A_1

As is inferred from graphical presentation of Figure 4.4, even though outcomes of this very experiment for environment A_1 shows a comparable behavior as a whole, yet it does not suggest a performance to be evaluated against the proposed correlation. It, therefore, will be

important to examine such an experiment for existence of a factor, apart from imposed variables, which could influence its outcomes. Thus, an agent of same knowledge was also introduced to an environment of a different layout in order to investigate existence of an artifact related to an environment of specific arrangement. Figure 4.5 represents this alternative environment. The agent is subject to aforementioned a, b, and c repetitions.

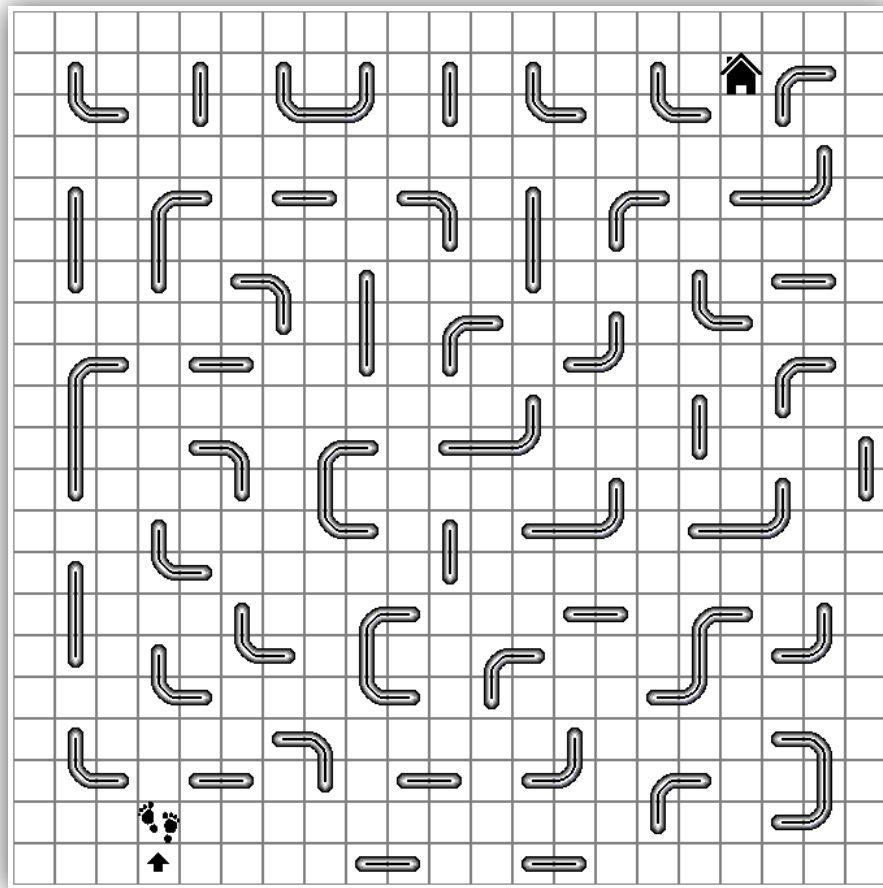


Figure 4.5 – Representation of Environment B_1 without Instruction (i.e., Cue)

The five hundred and one (501) observations for environment B_1, consistent with patterns of environment A_1, are summarized in Table 4.2. Similar to results of environment A_1, these outcomes can neither accommodate suggested correlation between extent of instruction offered

and magnitude of ensured effectiveness as demonstrated in Figure 4.6. Such a similarity among behavior of an agent in two environments of different layouts denies existence of artifact impact related to environment layout on comparability of suggested correlation and observed trend. Basically, the layout of the environment is not causing the behavior of the agent that is resulting with the varying degrees of instruction provided.

Table 4.2 – Summary of Outcomes for Environment B_1

Experiment Identification	Instruction Level (%)	Number of Repetitions	Movement History (Steps)		
			Minimum	Average	Maximum
b_B_1_0	0	50	31	37	47
c_B_1_10	10	50	31	38	51
c_B_1_20	20	50	31	38	51
c_B_1_30	30	50	31	38	55
c_B_1_40	40	50	31	47	67
c_B_1_50	50	50	31	38	75
c_B_1_60	60	50	31	34	49
c_B_1_70	70	50	31	35	73
c_B_1_80	80	50	31	33	47
c_B_1_90	90	50	31	36	49
a_B_1_100	100	1	31	31	31

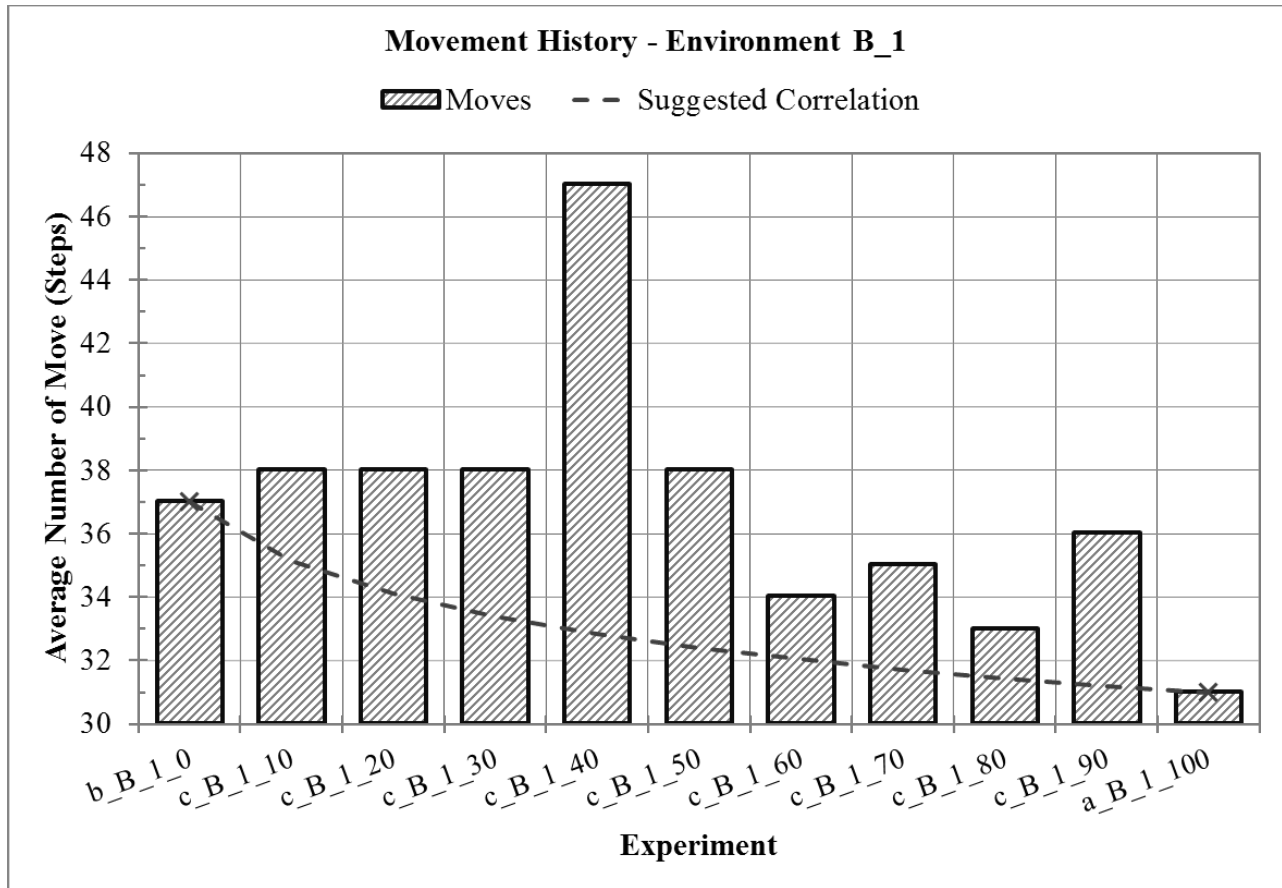


Figure 4.6 – Suggested Correlation amongst Performance Effectiveness and Instruction – Environment B_1

There is, however, a potential for misleading information which can be generated by randomness of location where an instruction is positioned. That is, randomness on basis of which an environment loses its instructions with 10% intervals may introduce an error in interpretation of outcomes. Environment A_2 was presented to a similar agent to investigate existence of an artifact associated with such randomness for location of an instruction. This environment is identical to environment A_1 in its layout yet not in the location of the provided instructions.

Figure 4.7 is the graphical presentation of outcomes for this experiment, which is summarized in Table 4.3, and disagrees with the existence of artifact in relation with randomness of location for an instruction.

Results of this very experiment manifest similar behavior for an agent against suggested correlation amongst instruction and performance effectiveness in comparison with its performance while it lives in environment A_1.

Table 4.3– Summary of Outcomes for Environment A_2

Experiment Identification	Instruction Level (%)	Number of Repetitions	Movement History (Steps)		
			Minimum	<i>Average</i>	Maximum
b_A_2_0	0	50	31	35	47
c_A_2_10	10	50	31	36	49
c_A_2_20	20	50	31	39	73
c_A_2_30	30	50	31	34	49
c_A_2_40	40	50	31	34	45
c_A_2_50	50	50	31	37	93
c_A_2_60	60	50	31	32	47
c_A_2_70	70	50	31	33	51
c_A_2_80	80	50	31	33	47
c_A_2_90	90	50	31	31	31
a_A_2_100	100	1	31	31	31

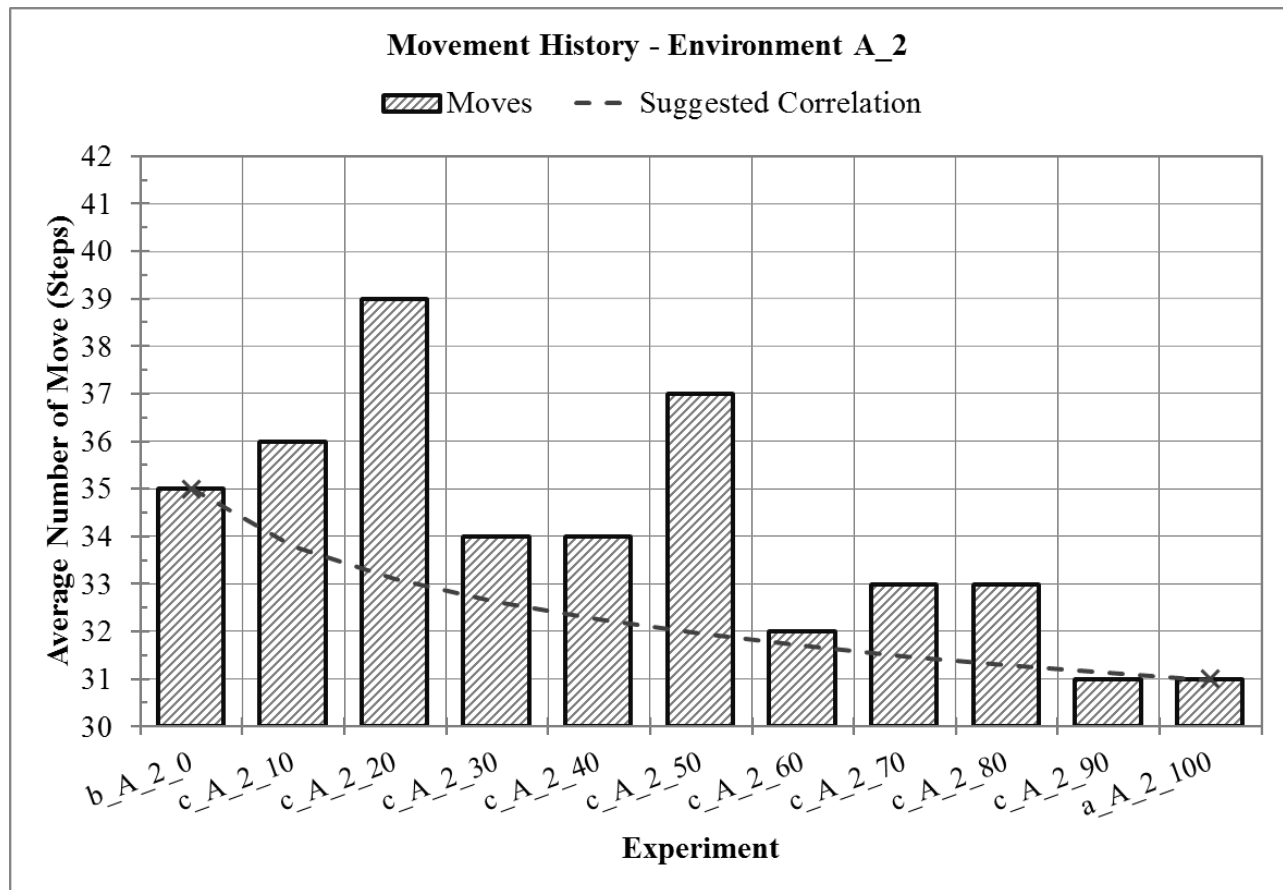


Figure 4.7 – Suggested Correlation amongst Performance Effectiveness and Instruction – Environment A_2

In order to test against existence of a combined artifact, which may be caused by combination of environment layout and randomness of location for instruction, an agent of similar knowledge level and decision-making capability is exposed to environment B_2 – an environment of similar layout with environment B_1 which offers instruction in different location in comparison with environment A_2. Observation outcomes are summarized in Table 4.4 and Figure 4.8.

Table 4.4 – Summary of Outcomes for Environment B_2

Experiment Identification	Instruction Level (%)	Number of Repetitions	Movement History (Steps)		
			Minimum	<i>Average</i>	Maximum
b_B_2_0	0	50	31	38	51
c_B_2_10	10	50	31	38	51
c_B_2_20	20	50	31	38	57
c_B_2_30	30	50	31	36	47
c_B_2_40	40	50	31	40	53
c_B_2_50	50	50	31	35	51
c_B_2_60	60	50	31	36	59
c_B_2_70	70	50	31	34	43
c_B_2_80	80	50	31	39	99
c_B_2_90	90	50	31	31	31
a_B_2_100	100	1	31	31	31

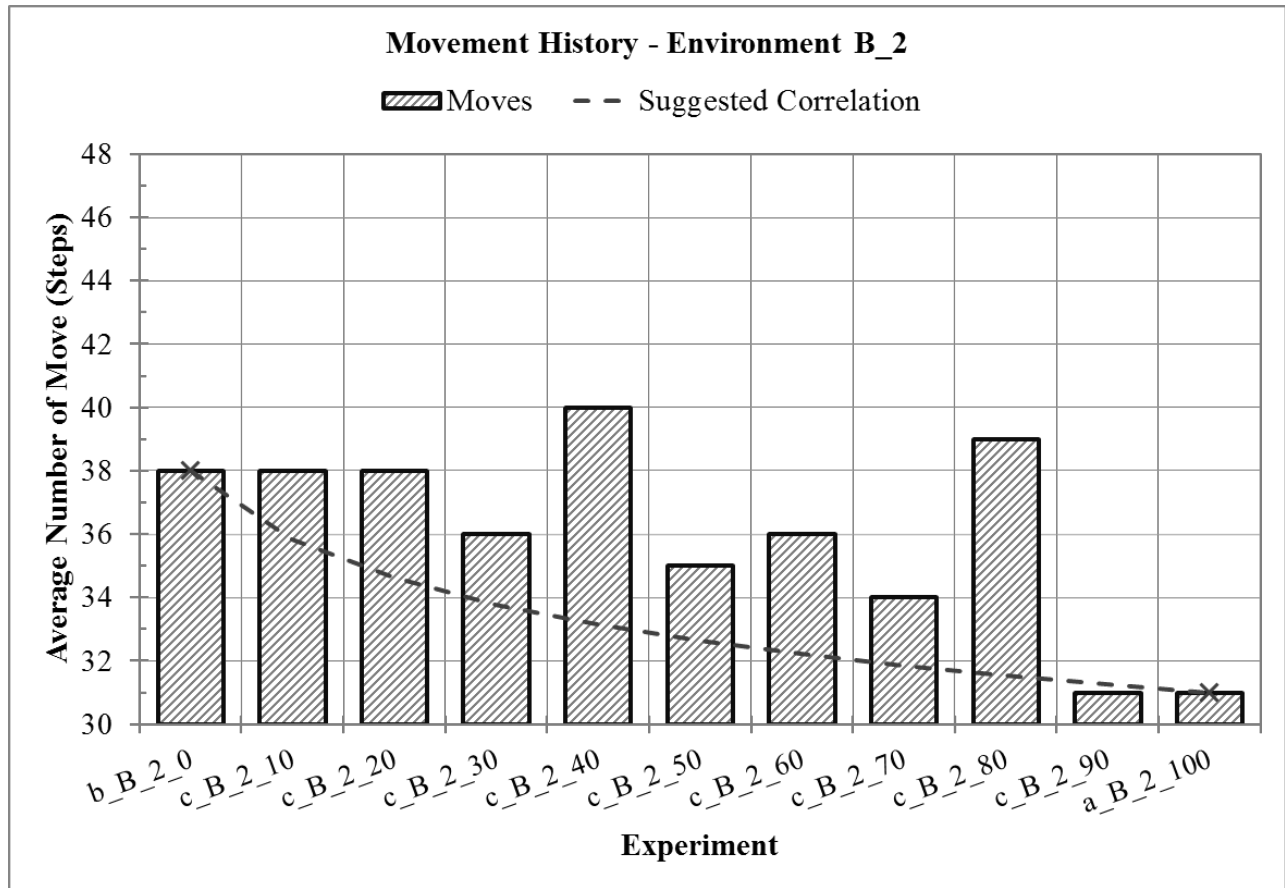


Figure 4.8 – Suggested Correlation amongst Performance Effectiveness and Instruction – Environment B_2

Observing the four above-mentioned experiments, within which exist two similar environment layouts and three (3) different instruction layouts, suggests that:

- i) in presence of equal level of instruction which are situated in identical locations, performance of an agent is influenced by an environment layout – i.e., ‘environment impact’; and
- ii) in an environment, performance of an agent is affected by location of instruction – i.e., ‘location impact’. Learning incapability of an agent legitimately agrees with such a conclusion since it cannot identify two similar environments and does not learn a lesson from its previously

conducted performance. This very conclusion did provide a better understanding of impact an instruction imposes on an agent's behavior. That is, presence of instruction only in a specific location affects behavior of an agent and improves effectiveness of its performance.

Figure 4.9 presents outcomes of another experiment in which location of instruction is different within environment A and does agree with such conclusion.

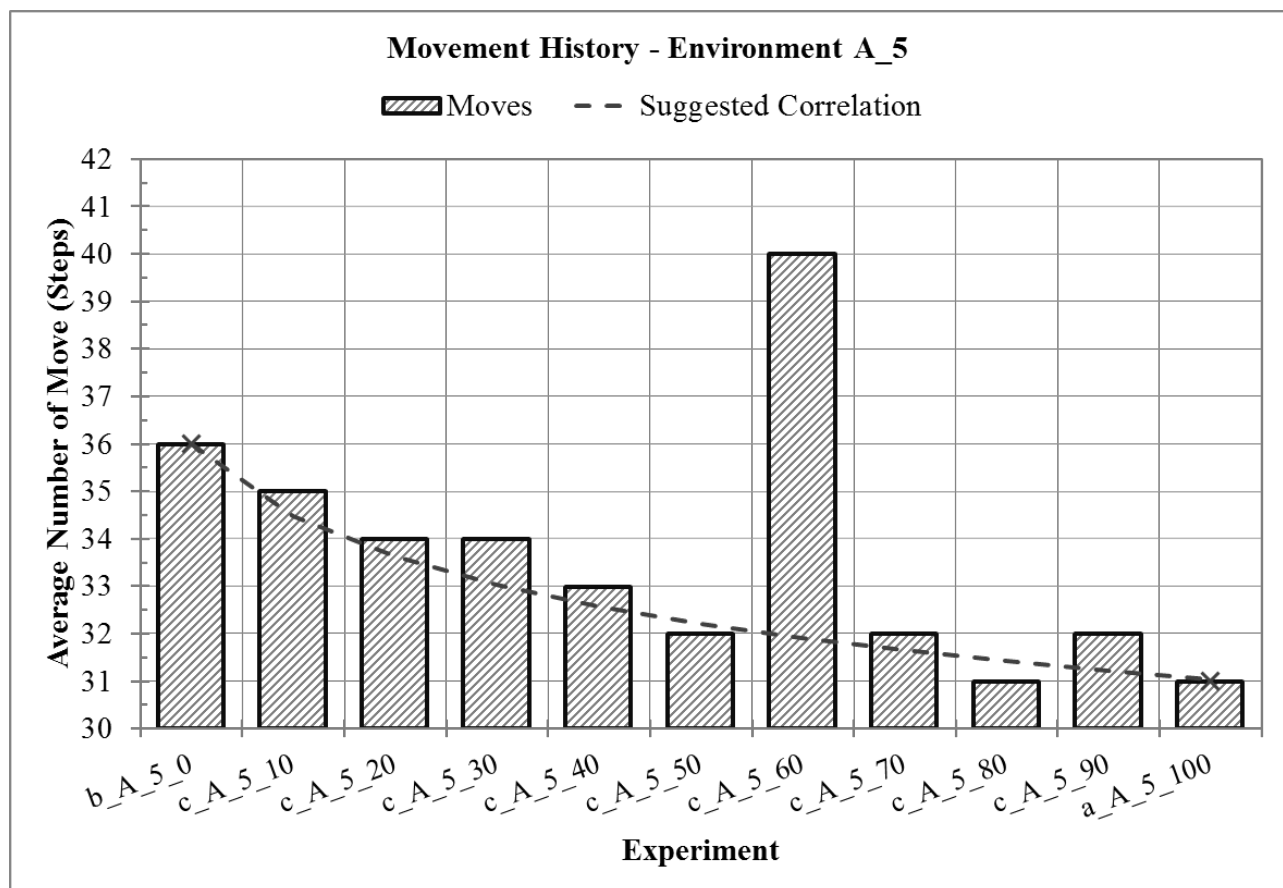


Figure 4.9 – Suggested Correlation amongst Performance Effectiveness and Instruction – Environment A_5

Outcomes of additional observations, which are reported in appendices, also prove these conclusions positive.

As is illustrated in Figure 4.1, it is assumed that performance of an agent is the most optimum while it visits locations between start and finish points where instruction (i.e., black-color diamond) is present. Within layout of this very environment, and for that matter an environment in general, there exist coordinates where considered key locations for presence of instruction. In a different analogy, a key location can represent a ‘complete-kit-concept’ requirement (Ronen, 1992), completion of which will deliver a value-added outcome. As illustrated in Figure 4.10, nine (9) locations within an environment A_1 are identified in where presence of instruction is critically leading and, thus, are required.

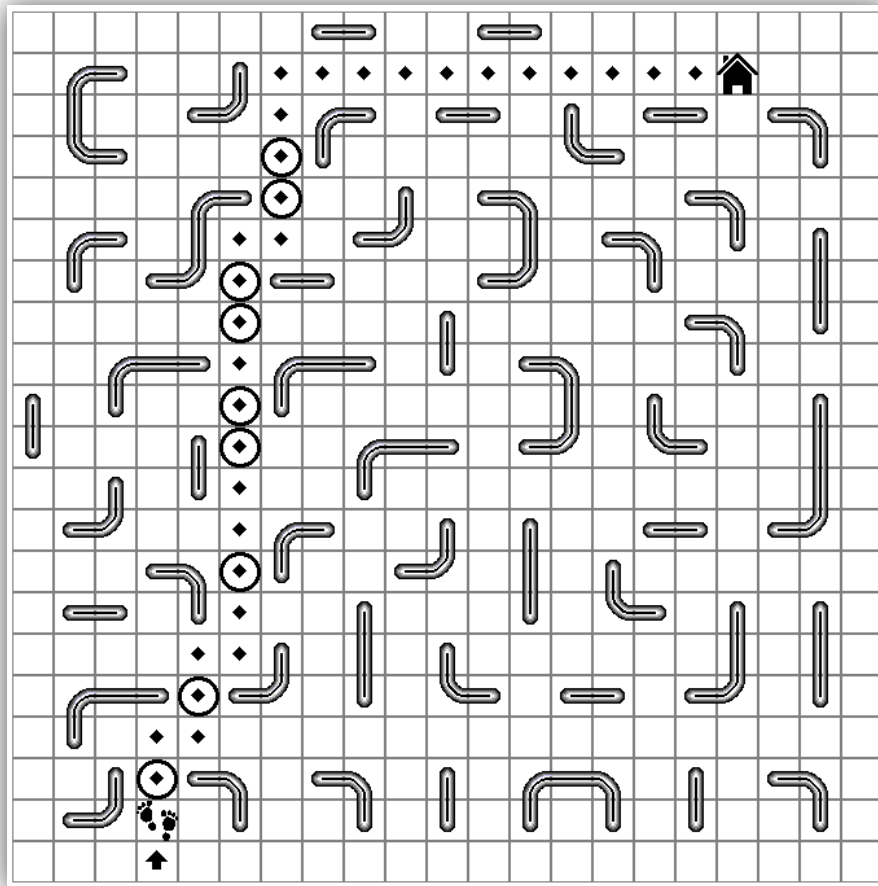


Figure 4.10 – Representation of Environment A_1 with Instruction and Key Location

In an environment A_1, an experiment a_A_1_100 in which instruction is removed from nine (9) random locations will represent an experiment c_A_70 of such an environment A:

(9 Missing Instruction) ÷ (31 Expected Steps, i.e., 100% Effectiveness) $\cong$ (30% Missing Instruction)

In other words, and for example, an experiment a_A_1_100 which misses thirty (30) percent – a total of nine (9) – of its instruction is a c_A_1_70 experiment. As Table 4.5 summarizes, existence of instruction in a key location proves to dominate performance effectiveness – an average reduction of fifty four (54) percent in this very observation.

Table 4.5 – Performance Effectiveness for Environment A at Presence of 70% Instruction

Experiment Identification	Instruction Level (%)	Number of Repetitions	Performance Effectiveness (%)
c_A_WOK_70 *	70	50	22
c_A_1_70	70	50	86
c_A_2_70	70	50	70
c_A_3_70	70	50	60
c_A_4_70	70	50	82
c_A_5_70	70	50	82

* c_A_WOK_70 (**W**ith **O**ut **K**ey): This experiment is a part of scenario c (i.e., cue) and refers to an environment A_K in which instruction is absent in the key location – an environment which offers seventy (70) percent instruction.

In accordance with key-location conclusion, environment A_K is designed to accommodate an agent where its performance is evaluated against the expected behavior. Figure 4.11

demonstrates an environment A_K in which required pieces of instruction are positioned in key locations.

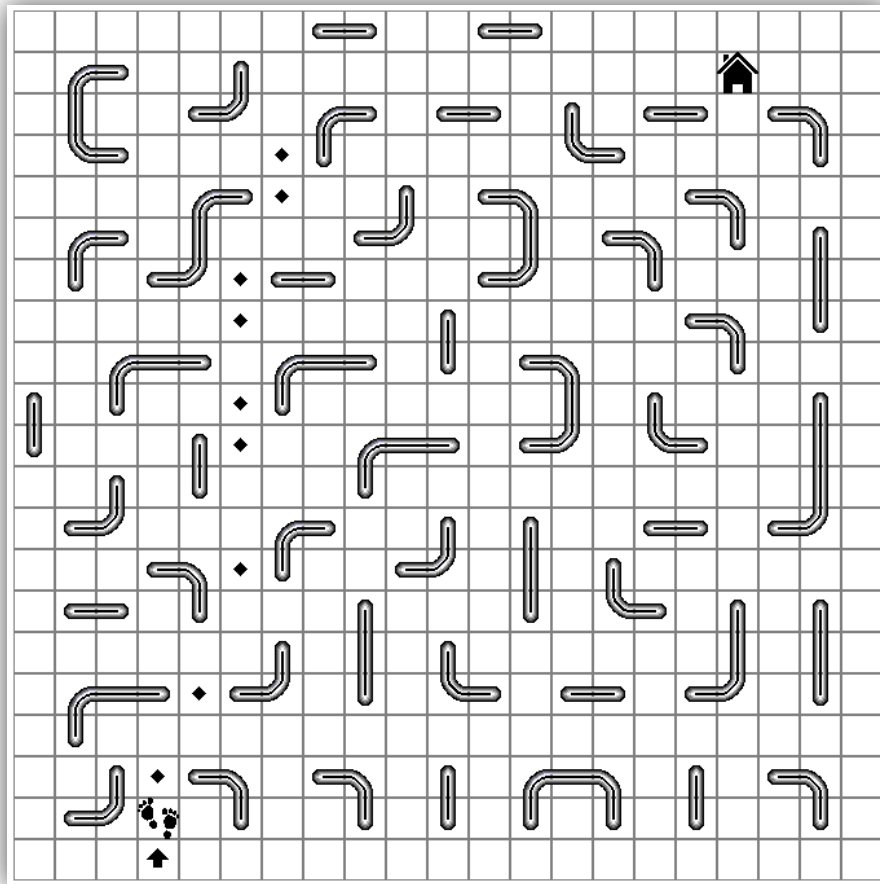


Figure 4.11 – Representation of an Environment A_K with Instruction (i.e., Signal)

As in experiments of other environments, an agent of identical knowledge and characteristics is exposed to environment A_K. This environment is in possession of hundred (100) percent of instruction (i.e., a_A_K_100). Upon completion of fifty (50) repetitions, an environment A_K of identical arrangement is introduced to a similar agent to accomplish its assignment while ten (10) percent of instruction is omitted as a set of fifty (50) repetitions is completed. Outcomes for these five hundred and one (501) experiments are summarized in Table 4.6.

Table 4.6 – Summary of Outcomes for Environment A_K

Experiment Identification	Instruction Level (%)	Number of Repetitions	Movement History (Steps)		
			Minimum	<i>Average</i>	Maximum
b_A_K_0	0	50	31	36	55
c_A_K_10	10	50	31	35	47
c_A_K_20	20	50	31	34	45
c_A_K_30	30	50	31	33	49
c_A_K_40	40	50	31	32	39
c_A_K_50	50	50	31	31	33
c_A_K_60	60	50	31	31	33
c_A_K_70	70	50	31	31	33
c_A_K_80	80	50	31	31	31
c_A_K_90	90	50	31	31	31
a_A_K_100	100	1	31	31	31

As expected and according to Figure 4.12, presence of instruction in a key location in environment A_K decreases average number of moves for its agent which travels between start point and destination – the fact which results in an ever increasing effectiveness in performance.

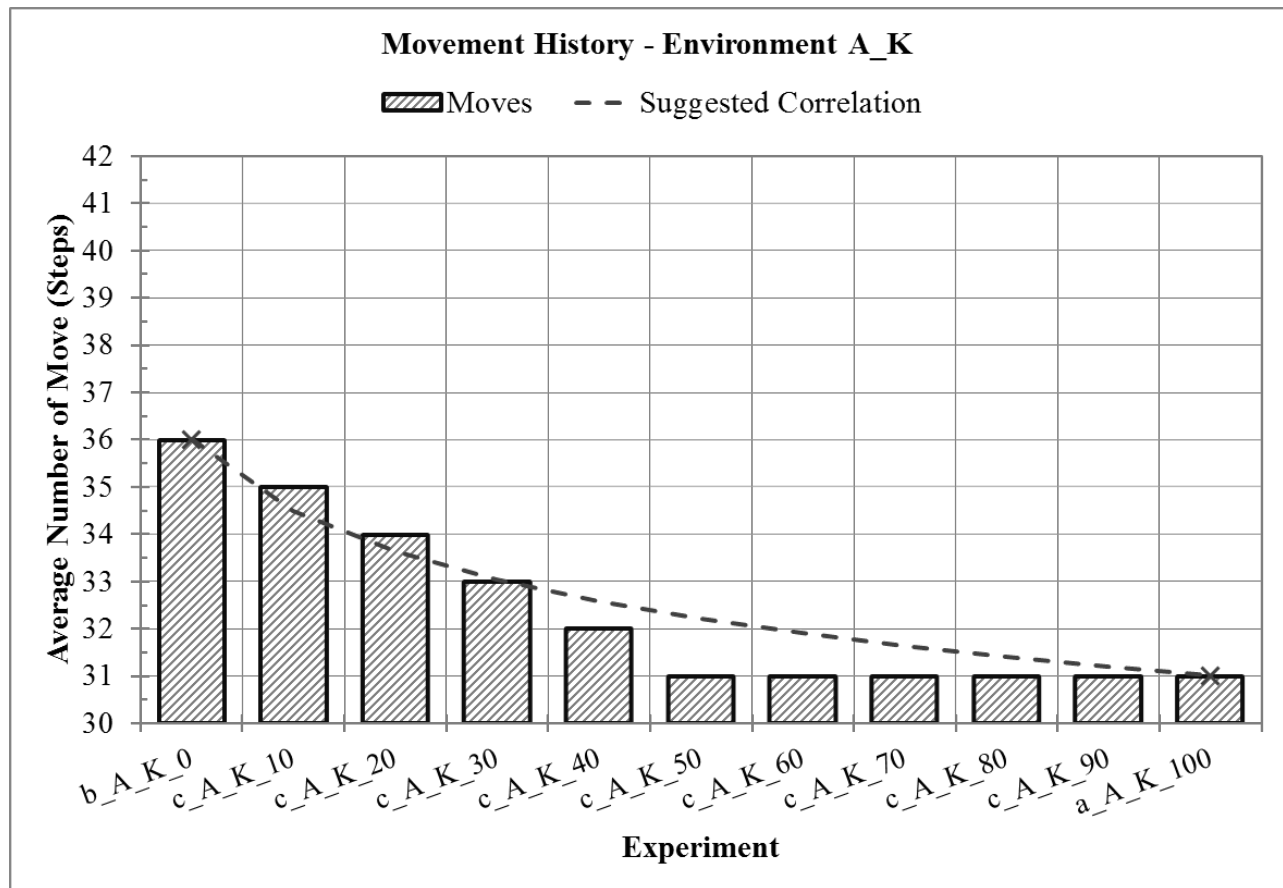


Figure 4.12 – Suggested Correlation amongst Performance Effectiveness and Instruction – Environment A_K

In accordance with conclusion on ‘location impact’, an environment B_K was introduced to an agent, where instruction was present in identified key locations. Although this very experiment did not agree with suggested correlation in whole, manipulation of bar chart – as is demonstrated with black-dashed line – offers similar observation as has been suggested by ‘environment impact’.

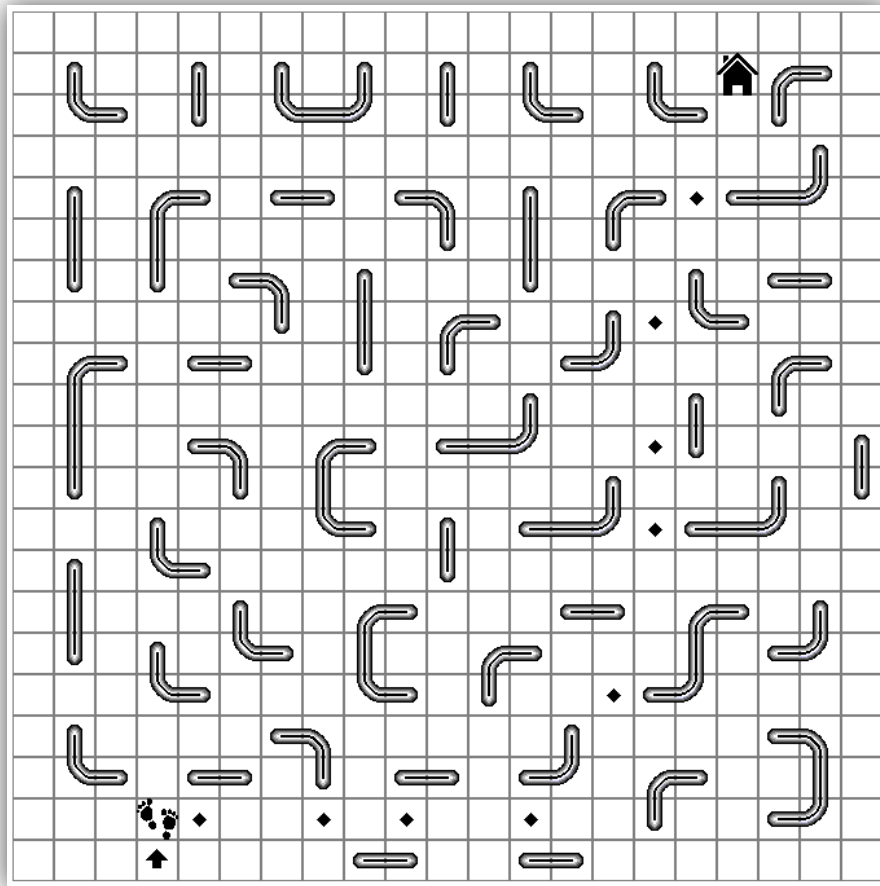


Figure 4.13 – Representation of an Environment B_K with Instruction (i.e., Signal)

A closer review of Figure 4.14, nevertheless, reveals that behavior of an agent does persist with similar trend as provided instruction in a key location is sixty (60) percent and more. Such manipulation in correlation with suggested ‘environment impact’ represent an idea of ‘complexity impact’.

Movement history for environment B_K is summarized in Table 4.7.

Table 4.7 – Summary of Outcomes for Environment B_K

Experiment Identification	Instruction Level (%)	Number of Repetitions	Movement History (Steps)		
			Minimum	<i>Average</i>	Maximum
b_B_K_0	0	50	31	36	55
c_B_K_10	10	50	31	40	51
c_B_K_20	20	50	31	39	51
c_B_K_30	30	50	31	40	53
c_B_K_40	40	50	31	41	49
c_B_K_50	50	50	31	<u>38</u>	49
c_B_K_60	60	50	31	<u>40</u>	53
c_B_K_70	70	50	31	<u>38</u>	53
c_B_K_80	80	50	31	<u>37</u>	53
c_B_K_90	90	50	31	<u>34</u>	41
a_B_K_100	100	1	31	<u>31</u>	31

The nine (9) experiments within environment B_K, and in particular those of sixty percent and more instruction, also confirm existence of a correlation in which effectiveness of performance is introduced as a dependent of ‘environment’ and ‘location’. Such confirmation will be a valid explanation for existence of relationship between ‘complexity’ and ‘instruction’. Studying outcomes of these experiments for environment B_K reveals that improvement of performance effectiveness in a ‘complex’ environment mandates presence of a minimum level of instruction – which in this case is sixty (60) percent – in identified key location.

Important to note is that such relationship cannot be observed within experiments of an environment A and environment B in which instruction is not designed to be presented in a ‘key location’ – i.e., absence, and for that matter presence, of instruction in a desired path is an

outcome of a random process. This randomness decreases likelihood of situating a piece of instruction in a required location; particularly in experiments in which only a small number of instruction is populated.

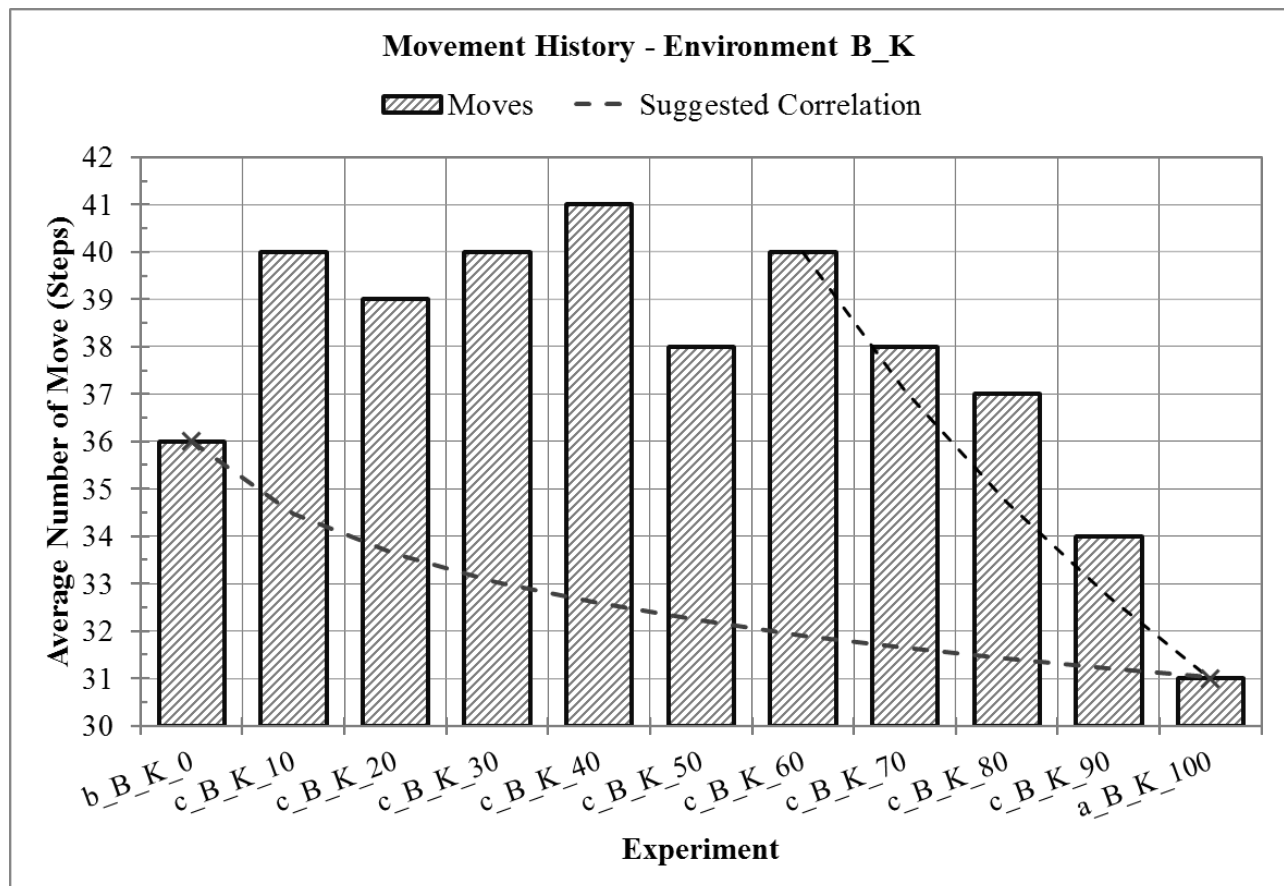


Figure 4.14 – Suggested Correlation amongst Performance Effectiveness and Instruction – Environment B_K

Therefore, conclusions on ‘environment impact’ and ‘location impact’ which were drawn on basis of earlier observations on environments A_1, A_2, B_1, and B_2 may be legitimately rephrased as ‘complexity impact’ and ‘location impact’, respectively. That is:

- i) in presence of equal level of instruction which are situated in identical locations, performance of an agent is influenced by ‘*complexity*’ of an environment – i.e., ‘complexity impact’; and
- ii) in an environment, performance of an agent is affected by location of instruction – i.e., ‘location impact’.

It is important to remember this investigation aims to explore influence of interpretation of a cue – which is imposed by absence of sufficient instruction – on accomplishment of a task. On this note, ‘complexity’ of a task which is to be delivered and ‘presence’ of instruction where it is needed – ‘key location’ in cases of experiments for this simulation – are two important attributes which govern effectiveness of a piece of instruction. Such effectiveness will consequently affect effectiveness of task execution and its delivery.

It also is worth mentioning that key location is a variable of a desired path between locations of start and finish. A key location refers to a coordinate where decision-making is supposedly critical. It can be a representation of a point when/where a set of necessary inputs is required for a successful accomplishment of an assignment. Absence of instruction, or rather sufficient instruction, in such strategic location may introduce a degree of deficiency to process of task accomplishment since it imposes interpretation of a cue from surroundings of a situation to understand an incomplete instruction or make sense of an imperfect piece of information.

(4.3) Discussion of Result

In the course of its execution, a construction project may accrue unexpected expense as a result of field decisions, some of which arise from incomplete and/or imperfect information. It is, in fact, absence of instruction (i.e., a signal) which represents a cue and leads its user toward a

decision which may cost an undesirable outcome. Although a decision of this nature is also influenced by different parameters such as knowledge of a user and complexity of task, none will compensate for insufficiency of required instruction. Caution should be taken in understanding of an expense: an undesired outcome for an event can be introduced as expenses such as waste in resources including, but not limited to, additional man-power, material, equipment, and time.

Analysis of results for simulation in this thesis has demonstrated importance of required instruction in space (e.g., location and time) is needed.

It can be observed in graphical outcomes of this simulation model that absence of perfect instruction when required in either of environment A and environment B generates some waste. In this thesis, concept of waste is defined as: i) excessive number of steps in comparison with expected value that takes an agent to its predetermined destination; and ii) number of steps an agent repeats while traveling from the start point to its destination.

Analysis of movement history for an agent within different environments – particularly in case of environment A_K – and amongst different experimentations shows that average number of moves adversely changes with increasing percentage of available instruction. This observation in case of other presented experiments proves that presence of required information when/where it is needed is an attribute in performance effectiveness of an agent. Imperfect instruction when/where – i.e., in location of each move – a perfect piece of information is needed to initiate an assignment, mandates an agent to employ available information in its surroundings – i.e., a cue – to infill imperfectness of provided instruction.

In course of this simulation, cues for an agent are a neighbor location which is obstructed with a wall, a neighbor location which is already visited, and a neighbor location which is available to accommodate a move.

Analysis of repeated movement history for an agent within different environments and amongst different experiments, however, does not reveal a new secret. Rather, results of analysis are in agreement with movement history and exhibit similar regimen – an adverse correlation of percentage of available information and number of repeated move.

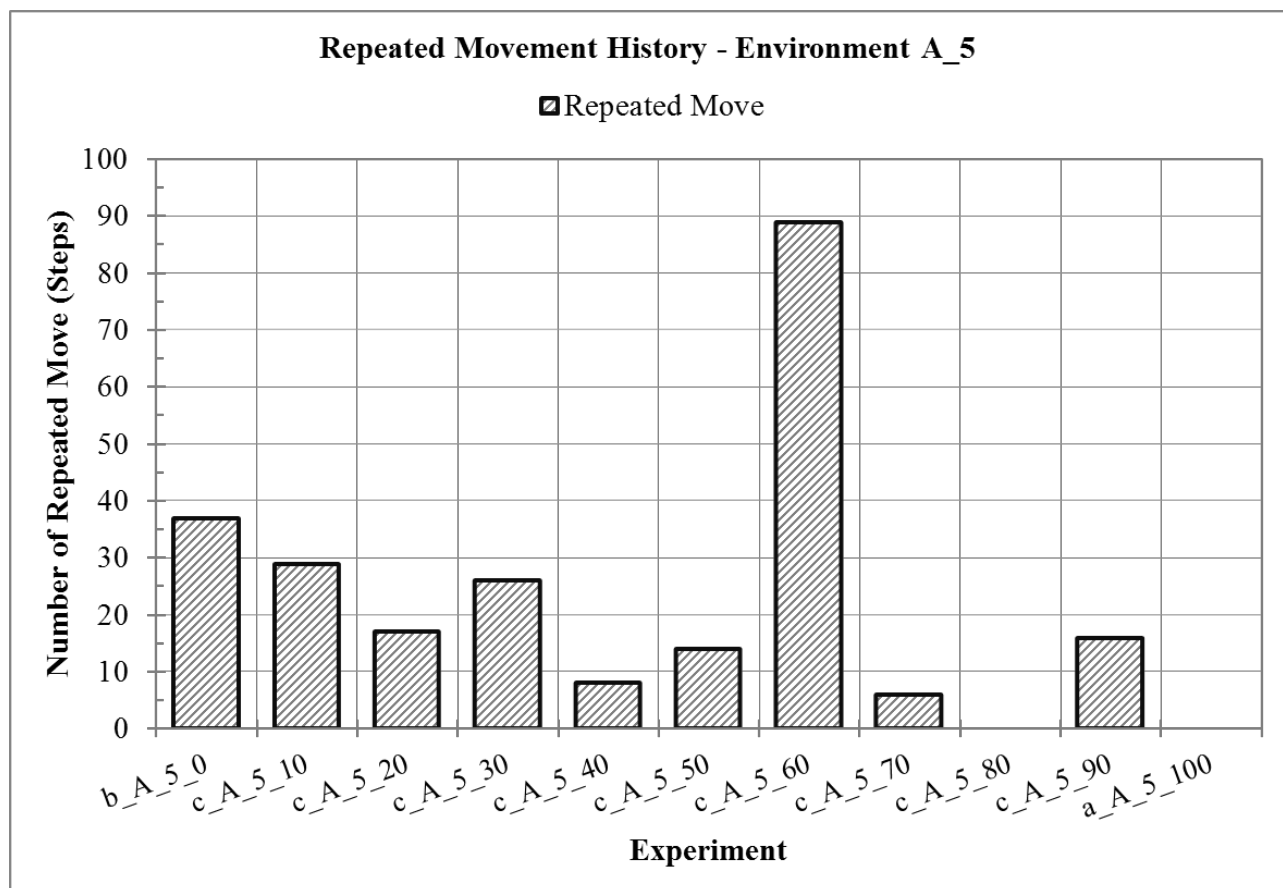


Figure 4.15 – Repeated Movement History – Environment A_5

When compared with its movement history, it can be understood from graphical presentation of repeated movement history that an average movement which takes more number of steps among different experiments in an environment tends to conclude in more number of repeated moves within the same environment. Figure 4.15 is an evidence for this observation: an agent in environment A_5 moved an average of forty (40) steps – the highest among eleven (11) experiments – to accomplish its experiment c_A_5_60. This performance also stands out in repeated movement history in which the agent re-visited eighty-nine (89) neighbor locations.

It can be understood from analysis of simulation results that increasing average number of moves is attributed by decision-making based on an available cue an agent locates in its surroundings. If, upon decreasing level of instruction, a non-optimal decision is made, an increasing average number of moves can be concluded. In contrast, as is presented in Figure 4.16, increasing level of instruction and perfect information in environment A_K results in less to none repeated movement – an observation which conclude in ever decreasing average number of moves. Similar analysis of repeated movement history for other experiments with environment A and environment B is reported in appendices.

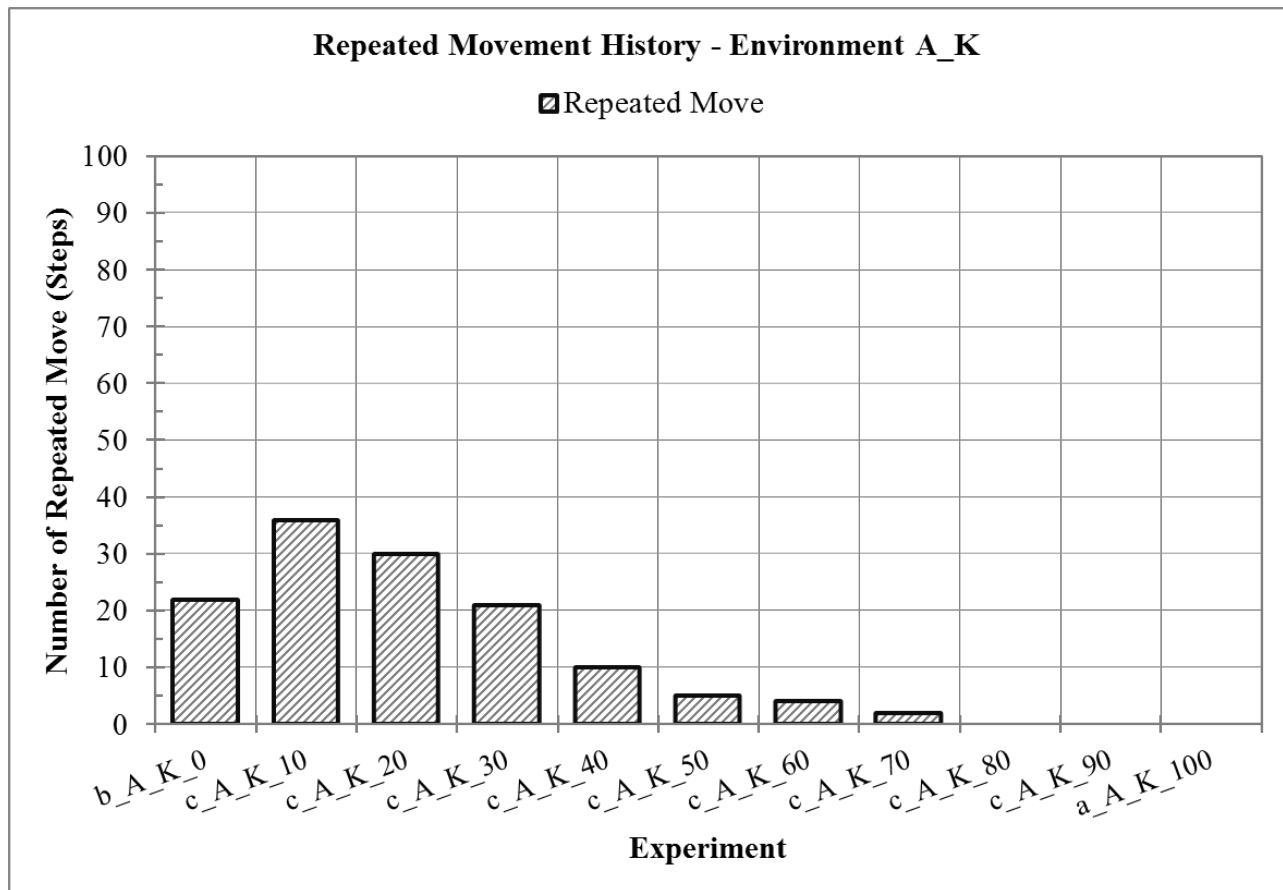


Figure 4.16 – Repeated Movement History – Environment A_K

In summary, as explicitness of instruction decreases, an increase in average number of moves may occur as an agent does not choose an optimal ‘what-to’ and: i) will have to complete a non-value-added ‘what-to’ in order to deliver the assigned task; and/or ii) will have to undo a non-value-added ‘what-to’ – i.e., a repeated movement – which consequently demands more number of moves. Thus, a correlation may be drawn between level of instruction, average number of moves, and total number of repeated moves.

As was demonstrated in Figure 4.1, the path-way in black-color diamond was assumed in the process of this investigation to be ‘the right thing’ – an effective ‘what-to’ do. On that note,

Figure 4.17 reveals that presence of more information will reduce probability of deviation from identifying ‘the right thing’ and, therefore, results in improved performance effectiveness. In other words, as level of offered information increases, there is a greater likelihood of commonly understanding an intended ‘what-to’ do and consequently ‘doing the right thing’

It should be mentioned that performance effectiveness of an agent in an environment was measured based on occurrence frequency of optimal performance – total number of cycles within fifty (50) repetitions in which an agent completes its assignment with 31 relocations.

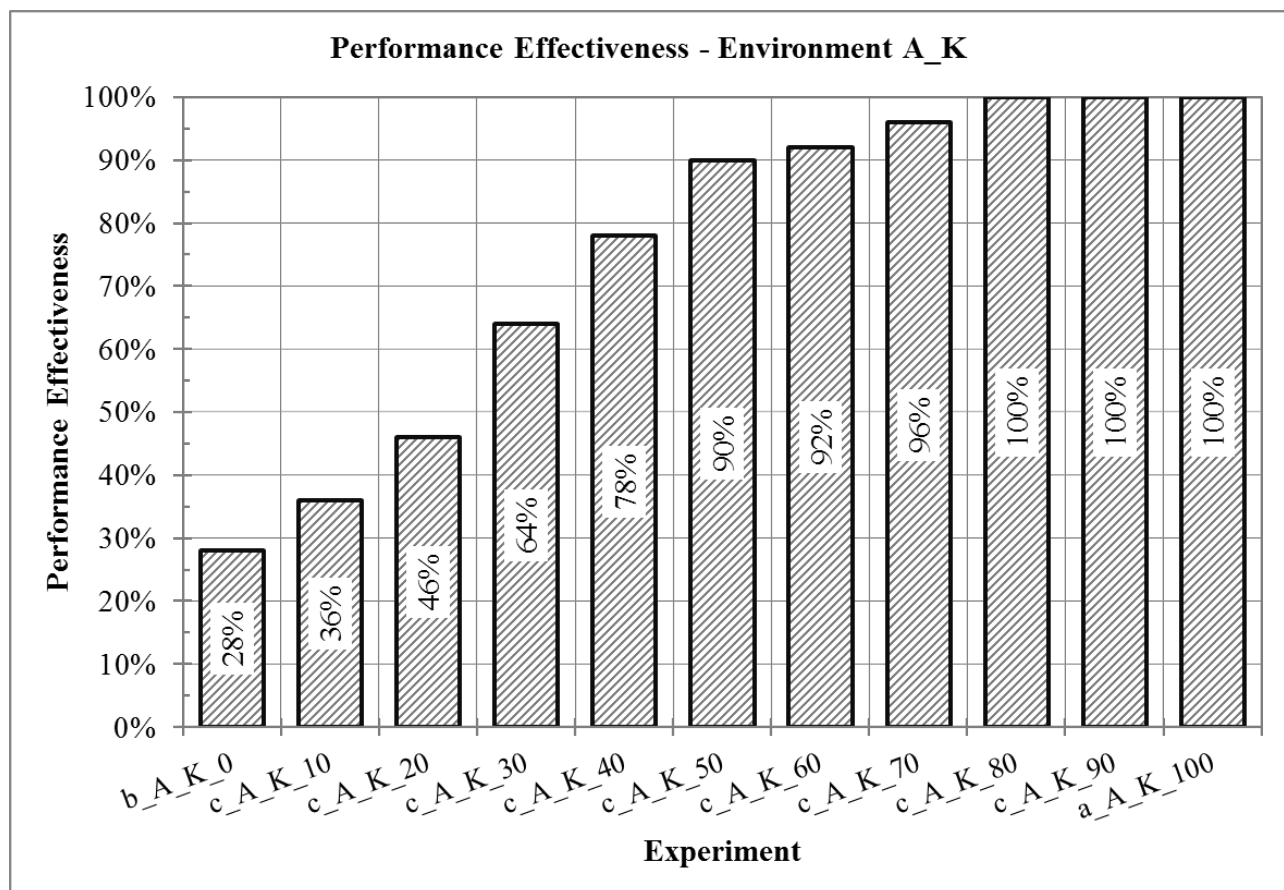


Figure 4.17 – Performance Effectiveness – Environment A_K

(4.4) Demonstration Case

In this section a few instances of cue-based decision-making are demonstrated. These instances – which were observed within different construction job sites – are solely to present that cue interpretation is a widely-spread phenomena and strongly disclaim any proof for concept of this thesis. Awareness of construction progress of these projects led the observer to judge that rendered decisions were on basis of cue-intprpretation.

(4.4.1) Space Identification Number

An educational building – in Michigan State University – is required to expand with external space to accommodate its needs for improvement. This additional space is designed as a four-story wing to be attached to the existing main structure. In each level, this new addition is divided into different spaces such as Breakout Space, Classroom, Conference Room, Hallway, and Office. In arrangement of this new wing, a Breakout Space refers to a furnished multi-purpose open area which is also known as an ‘informal meeting’ space. And in order to serve its intended purpose, it is supposed to meet the essential requirements of a multi-purpose accommodating space. A few of such needs can be data outlet, cooling utility, heating system, power supply, and voice line. Maintenance of these credentials from the perspective of facility planning and space management mandates a form of identification for this space. Thus, a number is assigned to each space and a sign is designed to present this identification number.

A shop-drawing is prepared in which is shown the location of each sign and its corresponding space. The responsible sub-contractor for fabrication (i.e., lettering and panel) and installation of these identification signs is assigned to follow instruction provided in the shop-drawing and to

deliver this task. Outcome of this assignment did not meet its expectation as several space identification signs were not addressed in accordance with provided shop-drawings.

What did happen? As previously stated, a Breakout space is recognized with an identification number solely in facility management documentations and such a space does not physically own a sign by which a public user can address it. Therefore, sequence of identification numbers in shop-drawing is interrupted and it seems that an identification sign is misplaced in its order.

In this very example, a) an office space located in the middle of corridor is identified 'B-253', b) its adjacent space being a Breakout space is identified 'B-254', which in a sequence identifies c) its following office space 'B-255'. This arrangement as presented in shop-drawing may be understood slightly different as a Breakout space does seem like an undesignated area – i.e., it is not classified in office category, yet it is not included in hallway space. Such an interruption offered a skilled trade an opportunity to skip Breakout space and recapture identification sequence with addressing the office space 'B-254' instead of 'B-255'.

Misplacement of abovementioned identification number as an undesired outcome was discovered when Key Shop realized incompatibility of assigned door lock-core, key labels, and shop-drawing with installed space identification numbers. A substantial volume of re-work and consequently monetary expenses were introduced as several departments were affected.

Absence of instruction in a key location forced its user to exercise decision-making and respond to existence of a cue. The Breakout space was not supposed to physically carry an identification sign while identified with a unique number on the shop-drawings. In knowledge of the sub-contractor, an open area where two hall-ways meet did not seem as a designated space (cue).

Therefore, instruction/information on shop-drawings which assigned this very space with an identification sign did not seem applicable to the task (misinterpretation). Such misinterpretation of provided information forced the sub-contractor to take advantage of the available cue to initiate, continue, and deliver the assignment.

(4.4.2) Pipe Color Coat

As a part of renovation process for a dining facility of a residence hall – in central part of Michigan State University campus – and while painting activity is in progress, it is realized by owner representative / inspector that in a location two pipes which mirror one another in functionality are not presented with identical color coat.

What did happen? A fire suppression pipe, which is marked with letter B in Figure 4.18, was supposed to be painted in same color as chilled and hot supply water pipes – i.e., brown. It was, however, painted in white since a similar fire suppression pipe which is labeled with letter A on the opposite side was painted in white. Neither the architect nor the project engineer approved this change and the painter was instructed to repaint Pipe B in color of chilled and hot water supply pipes.



Figure 4.18 – Incompatible Pipe Color Coat

Such a re-work demanded extensive coordination among construction project parties, although it appeared simple to the instructing party. Re-painting Pipe B required a suitable temperature – generally a surface temperature lower than fifty (50) degrees in Fahrenheit is not desirable as latex paint material will not dry quick enough on such surface temperature. Thus, the painter crew had to wait for a relatively warm day. Such a day coincided with scheduled installation of recycling and trash compactors, which postponed Pipe B re-painting and painting crew had to wait for another day of relative high temperature. The delay in re-painting Pipe B experienced more complication as time passed in waiting for another day with suitable temperature. An instance was the elevator equipment: railing had been installed and blocked access passage for painting crew. They, as a result, had to make scaffolding with aid of ladders. Apart from safety concerns, such circumstance could have damaged goods and have caused more difficulties.

The painter responded to existence of a cue, which was readily available to convey the missing piece of information, and delivered an undesired product. The painting crew did not understand the instruction specified color of paint coat for fire suppression pipe. The lack of common understanding between project design team and painting crew – let its reason be – imposed utilization of a cue: a similar fire suppression pipe in the opposite side which was painted in white.

(4.4.3) Upper Metal Stud Track

An Athletic department in an educational organization – Michigan State University – is in need of a bigger area in order to facilitate improvement in its Tele-marketing division. A vast storage space on the second floor, which is located under a portion of third upper seating deck in its Football stadium, is designed for alteration. An early activity in structural section is to construct an interior layer for every exterior wall of Concrete Masonry Units, also known as CMU, with metal studs and gypsum boards. As instructed in construction drawings (area of discussion is marked with a wavy-rectangle and pointed with an arrow in Figure 4.19), upper metal stud track for east exterior CMU wall is expected to be anchored right by the bottom side of a (presumably) non-functional gutter. This gutter is connected to a metal deck at location of its lowest elevation and is intended to collect precipitation which seeps through the third tier seating concrete deck and reaches this metal deck.

A similar task was completed by the same skilled trade crew some times prior to this new alteration project: construction of an interior layer for a CMU exterior wall where the upper track for metal studs was anchored to existing (presumably) non-functional gutter. It was, thus, strong enough of an evidence for skilled trade crew to, in agreement with construction drawings, fasten

upper metal stud track to similar platform. Water intrusion, however, shortly after completion of construction for this interior layer, interrupted project progress.

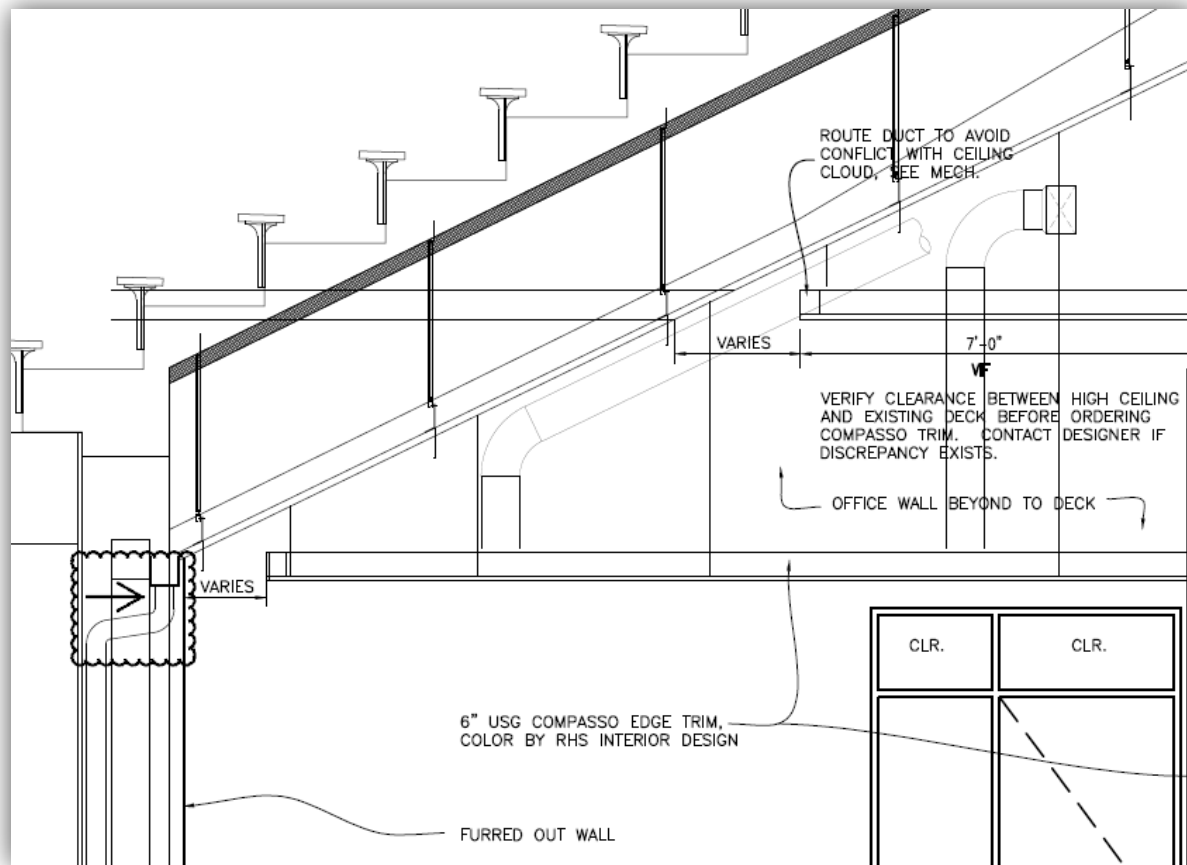


Figure 4.19 – Upper Metal Stud Track and Gutter – Construction-Drawing Instruction
 * Note: Only area which is indicated with a wavy-rectangle is relevant part of this figure.

What did happen? Third tier seating deck is furnished with concrete slabs where each expansion joint has been filled with bituminous sealant material. It was, however, realized that existing bituminous joint filler were damaged due to climate effects and precipitation water infiltrated expansion joints and did find its path to underlying sheet metal. Outflow water reaches the gutter in order to travel to a drain pipe. Where upper metal stud track was anchored at the bottom side of this gutter, however, leaked the water.



Figure 4.20 – Upper Metal Stud Track and Gutter – Construction Outcome

Construction drawing in this very example did not explicitly direct its user as to how such a structure should be constructed. Absence of instruction in its key location – i.e., a platform to which upper metal stud track should be anchored – resulted in re-work for structural crew as well as interior-finishing sub-contractor and delayed scheduled activities for other associated disciplines.

In this case, the receiver of instruction – i.e., carpentry skilled trade crew – received the message as it was intended, regardless that it was wrong. The knowledge and expertise of carpentry skilled trade crew questioned applicability of instruction to the area of work they faced.

However, similar construction details which were executed on a mirror location of the same building represented a cue, on basis of which carpentry skilled trade crew decided to follow construction-drawing instruction and deliver the assignment.

(4.4.4) Concrete Utility Trench

An auditorium located on the first level in an educational building was in need of renovation to accommodate advancement in education technology. This is a big semi arch shape room of three levels with its entrance positioned at the upper level. In process of renovation in this auditorium, electrical blueprint calls for roughing-in electrical conduit and installation of new power circuits in its in-place poured concrete floor so four new power adjustable tables can be utilized in four (4) corners of this space. The electrical note in construction drawings provided by design team instructs electrical skilled trade crew to “*trench concrete floor and install conduit box and circuit for new power adjustable table*”.



Figure 4.21 – Concrete Utility Trench – Demolition Outcome

What did happen? Concrete floor in North East, North West, and South West corners of auditorium was cut, blocks were removed, and requested tasks were completed. In South West corner, however, excavated foundation interrupted this electrical task. This interruption resulted in scope change which consequently brought about re-work and more work.

Instruction for opening a trench in concrete floor which was offered by construction design team was based on assumption of an unexcavated foundation. Such an assumption or rather decision was rendered on basis of poor judgment of existing condition which is not in interest of this investigation. Electrical skilled trade crew as the receiver in this communication process understood the intended message. This imperfect information was not known to electrical skilled trade crew and, therefore, there was no need to seek for a cue. Yet trenches which were cut in

concrete floor in North East, North West, and South West corners of work area voluntarily served as a cue: an excavated foundation.

(4.4.5) Non-adherent Paint Coat

In an educational building, the main office of an academic department requests for a low-budget renovation project. This will largely include addition of a wall (of metal studs and gypsum boards) in main office, installation of new carpet in office areas and hallways, and re-painting of entire area. The paint product which is used in this renovation project is latex-(water) based paint material. A month, or maybe two, after this renovation project is completed, the project management team receives a complaint from the academic department which reports existence of an area of loose surface layer (i.e., a peeling layer) of paint coat on newly color-coated wall.

Results of laboratory investigation revealed that existing layer of paint-coat on wall surface is an alkyd-epoxy-formula product.

What did happen? Construction shop drawings, on its Architectural notes, instruct to: “*Patch, prepare, and paint walls*”. Painting contractor whom was assigned with this project followed the directives in provided architectural drawing to patch, prepare, and paint.

Construction drawings and work-order instructed this contractor to prepare wall surfaces before application of the new paint coat. Such a broad term, forced the painting contractor to take advantage of readily available information (a cue) in its surroundings to initiate this assignment and prepare wall surfaces for the paint coat. Therefore, it was understood, or rather the painting contractor assumed, that a relatively-new educational building (i.e., constructed within past 20 years) which is primarily purposed for an office of academic department and classrooms, would

less likely have an existing layer of alkyd epoxy as a paint coat on its wall. An alkyd-epoxy-formula paint product is often utilized for color-coating surfaces in an environment where chemical solutions are frequently in use. Empirical experimentation has proved this paint product does not physically nor chemically bond with acrylic (latex-based) paint material.

Had architectural instruction stated such possibility, it would have saved resources which were utilized to complete re-work and eliminated expenses (e.g., accommodation, cost, time, manpower) associated with it.

At a glance, these occurrences and similar ones may seem negligible. And it can simply be concluded that it is often expected which are not commonly understood among project participants – an architect and an engineer for a project will comfortably criticize a similar occurrence by statements such as ‘should-have-known’ or ‘shouldn’t-have-happened’. It is, however, of significant value to understand why such an occurrence took place: why a decision was made and what its real impact was.

(4.5) Chapter Summary

In order to investigate existence of the impact of instruction on task delivery, an agent which represents a skilled trade worker was introduced to a virtual environment and was assigned to complete a task.

The environment was designed to pose three main scenarios: a) an environment S – Figure 4.1 – which had sufficient number of signs and considered an optimum case; b) an environment – as in Figure 4.3 – which offered no instruction (0% of optimal case); and c) an environment which carried incomplete (a percentage of optimum) instructions within an implicitness-explicitness

continuum to force its user to exercise decision-making. Insufficient instruction was present within a range of minimum 10% and maximum 90% of reference case with a 10% interval. An agent of a determined level of knowledge and incapable of learning, then, was expected to move in each of these environments from start point to the predetermined finish destination.

Chapter four (4), based on outcomes of analysis of presented simulation, presents an association among existence of instruction for task delivery and efficiency of performance. That is, performance experiences an ever increasing efficiency as extent of present instruction provided increases. On this very note, such efficiency was more so influenced by existence of instruction in its corresponding key space – i.e., what, when, and where it was critical.

Although limitation of simulation in this very investigation did result in design of an abstract Agent-Based simulation model, it was sufficiently descriptive as to how a task can be efficiently delivered when explicit directive is offered. And it, indeed, secures a common understanding of an assignment and its outcome among participants.

(5.0) Chapter Five – Conclusion

In working towards the goal of this research, which is to understand the impact that absence of instruction will have on production performance at the workplace, and as stated in Chapter One – Introduction, three (3) objectives were established.

The first objective ‘summarizing existing means and methods for modeling the situations workers face requiring cue interpretation in the workplace’ was accomplished in Chapter Two – Background. It was discussed that communication, which is an inevitable attribute of daily routines for a living entity, often refers to exchange of a thought, an idea, a piece of information, or alike between (at least) two living entities. This process of exchange is composed of four (4) steps:

- a) a thought, a concept, an idea, or a piece of knowledge which exists in mind of a living entity;
- b) a piece of information/a message which is prepared/encoded by a living entity – i.e., a sender – to be shared with another living entity. A sender is a source for information: a living entity which encodes her/his thought, idea, or knowledge in a form (e.g., a drawings with its corresponding notes and schedule) and then deliberately transmit it with use of a medium (e.g., a formal written order or an informal verbal instruction) a known receiver;
- c) a medium which delivers an encoded piece of information to another living entity – i.e., a receiver. Another entity which is supposed to receive an intentionally transmitted message is referred to as a receiver. A receiver decodes a delivered message into meaningful information in order to understand it and to accordingly make an action; and

d) an encoded piece of information/a message is comprehended by its receiver to be implemented. Note that comprehending a conveyed piece of information as intended is a function of ‘perception’ and ‘understanding’ of its user at a particular situation (Emmitt & Gorse, 2003).

This communication process should be an effective process in order to transmit the intention of a sender through its message to its receiver. It is often assumed that a receiver will interpret a transmitted piece of information as intended just because its sender understands it – an absolutely misleading assumption. A conveyed piece of information may not be as understandable for its receiver as is for its sender. Therefore, a potential for misinterpretation and misunderstanding in a communication process is always present. Misunderstanding or rather lack of common understanding between participants in a communication process is often induced by communication which is broken by barriers: i) information quality; and ii) information understandability. A broken communication will not deliver an intended message to its receiver. Consequently, such misinterpretation, let its reason be, forces the use of surroundings information (i.e., a cue) to make sense of an incomplete instruction. A cue generally refers to a ‘physical hint’ or ‘verbal hint’ which directs the executor of a task to act in a particular situation. In comparison with a signal, in other words, a cue represents an imperfect signal.

It can be summarized from observations of this explanatory investigation that an instruction always trumps a cue. Although it may compensate for incompleteness of a piece of information and meaninglessness of an instruction, a cue is not interpretable without (such) an instruction. The battle between an instruction and a cue begins as incompleteness of an instruction is

revealed. That is, imperfectness of an instruction triggers cue-seeking and forces cue interpretation.

The literature review also revealed that no study has quantified how imperfectness of an instruction, or rather information, impacts delivery of a task, although numerous studies have cited qualitative impacts. Literature has often pointed out incompleteness of information and ineffectiveness of a communication amongst variables which influence outcome of a process in its schedule (e.g., productivity) and cost (e.g., re-work).

The second objective, ‘developing an ABM computer-based simulation for cue interpretation at the workplace on a virtual construction job site’ was satisfied as outlined in Chapter Three – Method. In order to understand the influence of imperfect information on delivery of an assignment, a computer simulation technique was utilized and an abstract Agent-Based Model was designed using two approaches, namely, AgentSheets simulation tool and Python programming language. Virtual construction job sites utilized for observation of task-completion processes were presented in Figure 3.2. Functionality of these simulation models were detailed and demonstrated in Chapter Three – Method.

The third objective of ‘conducting simulation-based experiments to study cue interpretation at the workplace and its impact on work performance was met as described in Chapter Four – Analysis. Simulation repetitions were conducted to study the process and to conclude in its emerging results. Analysis of its outcomes demonstrates that as instruction improves in its completeness, an assignment is accomplished with less re-work and in a duration which is more comparable with the optimal solution.

(5.1) Contribution of Research

The prima facie results indicate that an explicit instruction will result in a better outcome compared to letting a skilled trade worker 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 an explicit instruction.

Referring to examples described in Chapter Four (4), Sections 4.3.1 through 4.3.4, although it undoubtedly was in interest of no participant in project to make an unsound decision, outcome of an incomplete/imperfect set of instruction turned into a waste – an effort of no value which cost projects unexpected expenses and delays.

These real-life instances also supported the analysis and findings of the simulations in which presentation of instructions in key locations was revealed. Absence of sufficient instruction in general, and its absence in a required points in particular, bring about ambiguity and force its recipient to resort to surrounding cues to further complete assignments.

It is common sense: the more that is known, the better an outcome becomes – an understanding with which conclusion of simulation experiments is in agreement. Such a virtual observation may be challenged in its legitimacy considering a fact that a simulation is often a very controlled phenomenon. However, when this concept is associated with different attributes in construction project management such as schedule performance, cost performance, safety performance, and generally productivity performance, the importance and impact of presence of sufficient instruction is beyond critical and cost of re-work due to absence of an explicit instruction is magnified.

This thesis contributes towards the understanding of the need for perfect information such that its recipients are not making decisions based on an environmental and/or a verbal cue. The quantification is hypothetical but nonetheless gives an order of magnitude of re-work that could happen when the provided instruction/information does not convey an intended message to its receiver.

(5.2) Limitation of Research

There are numerous qualitative measures and parameters which affect decision-making of individuals which were not included in the simulation model. This is a challenge to include but can be explored in future research. On that note, nevertheless, any decision which is rendered by a human being, deliberately or otherwise unknowingly, is influenced not only by knowledge he / she has about his / her surroundings but also with his / her expertise. And a construction skilled trade worker is not an exception to this statement. Thus, this investigation cannot be implemented in a construction job site as a skilled trade worker's decision is always influenced by his / her skill and past experiences – thus the modeling effort will need to capture much more complex dynamics.

Additionally, uniqueness of a construction project in its events plainly eliminates any chance by which an incident can be experienced twice. In other words, it is unexpected and certainly unplanned incidents which are induced (as this investigation is concerned) by lack of clear directives that bring about a non-repeatable project. Therefore, every construction project fairly represents a stand-alone story.

These environmental restraints in addition to technical restriction which is provoked by employed Agent-based simulation package AgentSheets, has resulted in an abstract model.

(5.3) Future Development of Research

Further research will be required to evaluate quality impact and its cost which is imposed by an incomplete piece of information and imperfect instruction

In addition, this abstract model, indeed, is in need of development in several aspects. One area of improvement is to enable an agent to obtain certain '*knowledge*' or better to say '*learn*' as it interacts with an environment – e.g., layout; pathway; etc. Such ability, supposedly, offers a fair amount of '*dependency*' in term of each decision which is made.

In addition to learning capability, it will be interesting to observe agents of different knowledge level (e.g., experience; skill; etc.) or '*understanding*' to an environment where an agent is expected to exercise decision-making based on its expertise and to behave in accordance with its crew dynamics.

APPENDIX

Java-Sourced Simulation Codes

```
import uAgentsheets.*;

public class Agent_Ground extends ActiveAgent {
    public Agent_Ground() {
        super(0, 0, null);
    }

    public Agent_Ground(int initRow, int initColumn, Agentsheet sheet) {
        super(initRow, initColumn, sheet);
    }

    public void method_20() {
        if (stacked_a("immediately above", "a", "agent_ground")) {
            erase(0, 0);
        }
        else if (see(0, 0, "agent_ground_pointer_blk")) {
            wait("0.25");
            new(-1, 0, "agent_worker_b");
            set("@cycle_agent_b", "to", "@cycle_agent_b + 1");
            plot_to_window("@move_agent_b", "in window", "movement history", "representing",
"moves", "between", "0", "and", "50", "using color:", 0x001000);
            plot_to_window("@correct_agent_b", "in window", "movement history", "representing",
"correct", "between", "0", "and", "50", "using color:", 0x009900);
            plot_to_window("@re_work_agent_b", "in window", "movement history",
"representing", "returns", "between", "0", "and", "50", "using color:", 0x0066ff);
            plot_to_window("@cycle_agent_b", "in window", "movement history", "representing",
"cycles", "between", "0", "and", "50", "using color:", 0xe80000);
        }
        else if (see(0, 0, "agent_ground_pointer_r")) {
            wait("0.25");
            new(1, 0, "agent_worker_r_3");
            set("@cycle_agent_r", "to", "@cycle_agent_r + 1");
            plot_to_window("@move_agent_r", "in window", "movement history", "representing",
"moves", "between", "0", "and", "50", "using color:", 0x001000);
            plot_to_window("@correct_agent_r", "in window", "movement history", "representing",
"correct", "between", "0", "and", "50", "using color:", 0x009900);
            plot_to_window("@re_work_agent_r", "in window", "movement history",
"representing", "returns", "between", "0", "and", "50", "using color:", 0x0066ff);
            plot_to_window("@cycle_agent_r", "in window", "movement history", "representing",
"cycles", "between", "0", "and", "50", "using color:", 0xe80000);
        }
    }
}
```

```

public void method_temp() {
    if (see(0, 0, "agent_ground_pointer_black")) {
        change(0, 0, "agent_ground");
        new(-1, 0, "agent_destination");
    }
    else if (see(0, 0, "agent_ground_pointer_r")) {
        new(1, 0, "agent_worker_r_3");
    }
}

}

import uAgentsheets.*;

public class Agent_Destination extends ActiveAgent {
    public Agent_Destination() {
        super(0, 0, null);
    }

    public Agent_Destination(int initRow, int initColumn, Agentsheet sheet) {
        super(initRow, initColumn, sheet);
    }

    public void method_10() {
        if (stacked_a("somewhere below", "a", "agent_worker_b")) {
            change(0, 0, "agent_destination");
            set("@x_b", "to", "3");
            set("@y_b", "to", "1");
            set("@move_agent_b", "to", "0");
            set("@correct_agent_b", "to", "0");
            set("@re_work_agent_b", "to", "0");
        }
        else if (stacked_a("somewhere below", "a", "agent_worker_r")) {
            change(0, 0, "agent_destination");
            set("@x_r", "to", "17");
            set("@y_r", "to", "19");
            set("@move_agent_r", "to", "0");
            set("@correct_agent_r", "to", "0");
            set("@re_work_agent_r", "to", "0");
        }
    }

    public void method_temp() {
        if (see(0, 0, "agent_destination")) {

```

```

        change(-1, 0, "agent_ground_pointer_r");
        erase(0, 0);
    }
}

import uAgentsheets.*;

public class Agent_Wall extends ActiveAgent {
    public Agent_Wall() {
        super(0, 0, null);
    }

    public Agent_Wall(int initRow, int initColumn, Agentsheet sheet) {
        super(initRow, initColumn, sheet);
    }
}

import uAgentsheets.*;

public class Agent_Worker_B extends ActiveAgent {
    public Agent_Worker_B() {
        super(0, 0, null);
    }

    public Agent_Worker_B(int initRow, int initColumn, Agentsheet sheet) {
        super(initRow, initColumn, sheet);
    }

    public void method_temporary() {
        if (see_a(0, 0, "agent_worker_b")) {
            erase(0, 0);
            broadcast("agent_destination", "method_temp");
            broadcast("agent_ground", "method_temp");
        }
    }

    public void while_running() {
        if (is("@cycle_agent_b", "=", "50")) {
            reset_simulation();
        }
        else if (next_to("=", "1", "agent_destination")) {

```

```

        make(0, 0, "destination");
    }
    else if (next_to(">", "0", "agent_ground_helper_key")) {
        make(0, 0, "method_4");
    }
    else if (next_to(">", "0", "agent_ground_helper_green")) {
        make(0, 0, "method_4");
    }
    else if (stacked_a("immediately above", "a", "agent_ground")) {
        make(0, 0, "method_0");
    }
}

public void method_0() {
    if (is("@x_b", "<", "17") && is("@y_b", "<", "19")) {
        make(0, 0, "neighbor_north_east");
    }
    else if (is("@x_b", "<", "17") && is("@y_b", "=", "19")) {
        make(0, 0, "neighbor_east");
    }
    else if (is("@x_b", "<", "17") && is("@y_b", ">", "19")) {
        make(0, 0, "neighbor_east_south");
    }
    else if (is("@x_b", "=", "17") && is("@y_b", "<", "19")) {
        make(0, 0, "neighbor_north");
    }
    else if (is("@x_b", "=", "17") && is("@y_b", ">", "19")) {
        make(0, 0, "neighbor_south");
    }
    else if (is("@x_b", ">", "17") && is("@y_b", "<", "19")) {
        make(0, 0, "neighbor_north_west");
    }
    else if (is("@x_b", ">", "17") && is("@y_b", "=", "19")) {
        make(0, 0, "neighbor_west");
    }
    else if (is("@x_b", ">", "17") && is("@y_b", ">", "19")) {
        make(0, 0, "neighbor_south_west");
    }
}

public void method_1() {
    if (see_a(-1, 0, "agent_wall") && see_a(0, 1, "agent_wall") && see(1, 0,
"agent_ground_helper_red") && see(0, -1, "agent_ground_helper_red")) {
        make(0, 0, "method_2");
    }
}

```

```

    else if (see_a(0, 1, "agent_wall") && see_a(1, 0, "agent_wall") && see(0, -1,
"agent_ground_helper_red") && see(-1, 0, "agent_ground_helper_red")) {
        make(0, 0, "method_2");
    }
    else if (see_a(1, 0, "agent_wall") && see_a(0, -1, "agent_wall") && see(-1, 0,
"agent_ground_helper_red") && see(0, 1, "agent_ground_helper_red")) {
        make(0, 0, "method_2");
    }
    else if (see_a(0, -1, "agent_wall") && see_a(-1, 0, "agent_wall") && see(0, 1,
"agent_ground_helper_red") && see(1, 0, "agent_ground_helper_red")) {
        make(0, 0, "method_2");
    }
    else if (see_a(-1, 0, "agent_wall") && see_a(1, 0, "agent_wall") && see(0, 1,
"agent_ground_helper_red") && see(0, -1, "agent_ground_helper_red")) {
        make(0, 0, "method_2");
    }
    else if (see_a(0, 1, "agent_wall") && see_a(0, -1, "agent_wall") && see(-1, 0,
"agent_ground_helper_red") && see(1, 0, "agent_ground_helper_red")) {
        make(0, 0, "method_2");
    }
    else if (see_a(-1, 0, "agent_wall") && see_a(0, 1, "agent_wall") && see(1, 0,
"agent_ground_helper_red")) {
        make(0, 0, "method_2");
    }
    else if (see_a(-1, 0, "agent_wall") && see_a(0, 1, "agent_wall") && see(0, -1,
"agent_ground_helper_red")) {
        make(0, 0, "method_2");
    }
    else if (see_a(0, 1, "agent_wall") && see_a(1, 0, "agent_wall") && see(-1, 0,
"agent_ground_helper_red")) {
        make(0, 0, "method_2");
    }
    else if (see_a(0, 1, "agent_wall") && see_a(1, 0, "agent_wall") && see(0, -1,
"agent_ground_helper_red")) {
        make(0, 0, "method_2");
    }
    else if (see_a(1, 0, "agent_wall") && see_a(0, -1, "agent_wall") && see(-1, 0,
"agent_ground_helper_red")) {
        make(0, 0, "method_2");
    }
    else if (see_a(1, 0, "agent_wall") && see_a(0, -1, "agent_wall") && see(0, 1,
"agent_ground_helper_red")) {
        make(0, 0, "method_2");
    }
    else if (see_a(0, -1, "agent_wall") && see_a(-1, 0, "agent_wall") && see(1, 0,
"agent_ground_helper_red")) {

```

```

        make(0, 0, "method_2");
    }
    else if (see_a(0, -1, "agent_wall") && see_a(-1, 0, "agent_wall") && see(0, 1,
"agent_ground_helper_red")) {
        make(0, 0, "method_2");
    }
    else if (see_a(0, -1, "agent_wall") && see_a(-1, 0, "agent_wall") && see(1, 0,
"agent_ground_helper_red")) {
        make(0, 0, "method_2");
    }
    else if (see_a(0, -1, "agent_wall") && see_a(-1, 0, "agent_wall") && see(0, 1,
"agent_ground_helper_red")) {
        make(0, 0, "method_2");
    }
    else if (see_a(0, 1, "agent_wall") && see_a(0, -1, "agent_wall") && see(-1, 0,
"agent_ground_helper_red")) {
        make(0, 0, "method_2");
    }
    else if (see_a(0, 1, "agent_wall") && see_a(0, -1, "agent_wall") && see(1, 0,
"agent_ground_helper_red")) {
        make(0, 0, "method_2");
    }
    else if (see_a(-1, 0, "agent_wall") && see_a(0, 1, "agent_wall") && see_a(1, 0,
"agent_wall")) {
        make(0, 0, "method_2");
    }
    else if (see_a(0, 1, "agent_wall") && see_a(-1, 0, "agent_wall") && see_a(0, -1,
"agent_wall")) {
        make(0, 0, "method_2");
    }
    else if (see_a(1, 0, "agent_wall") && see_a(0, -1, "agent_wall") && see_a(-1, 0,
"agent_wall")) {
        make(0, 0, "method_2");
    }
    else if (see_a(0, 1, "agent_wall") && see_a(1, 0, "agent_wall") && see_a(0, -1,
"agent_wall")) {
        make(0, 0, "method_2");
    }
    else if (see_a(-1, 0, "agent_wall") && see_a(0, 1, "agent_wall")) {
        make(0, 0, "neighbor_south_west");
    }
    else if (see_a(0, 1, "agent_wall") && see_a(1, 0, "agent_wall")) {
        make(0, 0, "neighbor_north_east");
    }
    else if (see_a(1, 0, "agent_wall") && see_a(0, -1, "agent_wall")) {
        make(0, 0, "neighbor_north_east");
    }

```

```

    }
    else if (see_a(0, -1, "agent_wall") && see_a(-1, 0, "agent_wall")) {
        make(0, 0, "neighbor_east_south");
    }
    else if (see_a(-1, 0, "agent_wall") && see_a(1, 0, "agent_wall")) {
        make(0, 0, "neighbor_east_west");
    }
    else if (see_a(0, 1, "agent_wall") && see_a(0, -1, "agent_wall")) {
        make(0, 0, "neighbor_north_south");
    }
    else if (see_a(-1, 0, "agent_wall")) {
        make(0, 0, "neighbor_east_south_west");
    }
    else if (see_a(0, 1, "agent_wall")) {
        make(0, 0, "neighbor_south_west_north");
    }
    else if (see_a(1, 0, "agent_wall")) {
        make(0, 0, "neighbor_west_north_east");
    }
    else if (see_a(0, -1, "agent_wall")) {
        make(0, 0, "neighbor_north_east_south");
    }
}

```

```

public void method_2() {
    if (see(-1, 0, "agent_ground")) {
        make(0, 0, "neighbor_north");
    }
    else if (see(0, 1, "agent_ground")) {
        make(0, 0, "neighbor_east");
    }
    else if (see(1, 0, "agent_ground")) {
        make(0, 0, "neighbor_south");
    }
    else if (see(0, -1, "agent_ground")) {
        make(0, 0, "neighbor_west");
    }
    else if (see(-1, 0, "agent_ground_helper_red")) {
        change(-1, 0, "agent_ground");
        make(0, 0, "neighbor_north_revst");
        set("@re_work_agent_b", "to", "@re_work_agent_b + 1");
    }
    else if (see(0, 1, "agent_ground_helper_red")) {
        change(0, 1, "agent_ground");
        make(0, 0, "neighbor_east_revst");
        set("@re_work_agent_b", "to", "@re_work_agent_b + 1");
    }
}

```

```

    }
    else if (see(1, 0, "agent_ground_helper_red")) {
        change(1, 0, "agent_ground");
        make(0, 0, "neighbor_south_revst");
        set("@re_work_agent_b", "to", "@re_work_agent_b + 1");
    }
    else if (see(0, -1, "agent_ground_helper_red")) {
        change(0, -1, "agent_ground");
        make(0, 0, "neighbor_west_revst");
        set("@re_work_agent_b", "to", "@re_work_agent_b + 1");
    }
}

public void method_off() {
    if (see(-1, 0, "agent_ground")) {
        make(0, 0, "neighbor_north");
    }
    else if (see(0, 1, "agent_ground")) {
        make(0, 0, "neighbor_east");
    }
    else if (see(1, 0, "agent_ground")) {
        make(0, 0, "neighbor_south");
    }
    else if (see(0, -1, "agent_ground")) {
        make(0, 0, "neighbor_west");
    }
}

public void method_4() {
    if (see(-1, 0, "agent_ground_helper_key")) {
        change(0, 0, "agent_worker_b");
        move(-1, 0);
        new(1, 0, "agent_ground_helper_red");
        set("@move_agent_b", "to", "@move_agent_b + 1");
        set("@correct_agent_b", "to", "@correct_agent_b + 1");
        set("@y_b", "to", "@y_b + 1");
    }
    else if (see(0, 1, "agent_ground_helper_key")) {
        change(0, 0, "agent_worker_b_e");
        move(0, 1);
        new(0, -1, "agent_ground_helper_red");
        set("@move_agent_b", "to", "@move_agent_b + 1");
        set("@correct_agent_b", "to", "@correct_agent_b + 1");
        set("@x_b", "to", "@x_b + 1");
    }
    else if (see(1, 0, "agent_ground_helper_key")) {

```

```

    change(0, 0, "agent_worker_b_s");
    move(1, 0);
    new(-1, 0, "agent_ground_helper_red");
    set("@move_agent_b", "to", "@move_agent_b + 1");
    set("@correct_agent_b", "to", "@correct_agent_b + 1");
    set("@y_b", "to", "@y_b - 1");
}
else if (see(0, -1, "agent_ground_helper_key")) {
    change(0, 0, "agent_worker_b_w");
    move(0, -1);
    new(0, 1, "agent_ground_helper_red");
    set("@move_agent_b", "to", "@move_agent_b + 1");
    set("@correct_agent_b", "to", "@correct_agent_b + 1");
    set("@x_b", "to", "@x_b - 1");
}
else if (see(-1, 0, "agent_ground_helper_green")) {
    change(0, 0, "agent_worker_b");
    move(-1, 0);
    new(1, 0, "agent_ground_helper_red");
    set("@move_agent_b", "to", "@move_agent_b + 1");
    set("@correct_agent_b", "to", "@correct_agent_b + 1");
    set("@y_b", "to", "@y_b + 1");
}
else if (see(0, 1, "agent_ground_helper_green")) {
    change(0, 0, "agent_worker_b_e");
    move(0, 1);
    new(0, -1, "agent_ground_helper_red");
    set("@move_agent_b", "to", "@move_agent_b + 1");
    set("@correct_agent_b", "to", "@correct_agent_b + 1");
    set("@x_b", "to", "@x_b + 1");
}
else if (see(1, 0, "agent_ground_helper_green")) {
    change(0, 0, "agent_worker_b_s");
    move(1, 0);
    new(-1, 0, "agent_ground_helper_red");
    set("@move_agent_b", "to", "@move_agent_b + 1");
    set("@correct_agent_b", "to", "@correct_agent_b + 1");
    set("@y_b", "to", "@y_b - 1");
}
else if (see(0, -1, "agent_ground_helper_green")) {
    change(0, 0, "agent_worker_b_w");
    move(0, -1);
    new(0, 1, "agent_ground_helper_red");
    set("@move_agent_b", "to", "@move_agent_b + 1");
    set("@correct_agent_b", "to", "@correct_agent_b + 1");
    set("@x_b", "to", "@x_b - 1");
}

```

```

    }
    else if (stacked_a("immediately above", "a", "agent_ground")) {
        make(0, 0, "method_0");
    }
}

```

```

public void neighbor_north() {
    if (see_a(-1, 0, "agent_wall")) {
        make(0, 0, "method_1");
    }
    else if (see(-1, 0, "agent_ground")) {
        change(0, 0, "agent_worker_b");
        move(-1, 0);
        new(1, 0, "agent_ground_helper_red");
        set("@move_agent_b", "to", "@move_agent_b + 1");
        set("@y_b", "to", "@y_b + 1");
    }
    else if (see(0, 1, "agent_ground") && %_chance("33")) {
        change(0, 0, "agent_worker_b_e");
        move(0, 1);
        new(0, -1, "agent_ground_helper_red");
        set("@move_agent_b", "to", "@move_agent_b + 1");
        set("@x_b", "to", "@x_b + 1");
    }
    else if (see(1, 0, "agent_ground") && %_chance("33")) {
        change(0, 0, "agent_worker_b_s");
        move(1, 0);
        new(-1, 0, "agent_ground_helper_red");
        set("@move_agent_b", "to", "@move_agent_b + 1");
        set("@y_b", "to", "@y_b - 1");
    }
    else if (see(0, -1, "agent_ground") && %_chance("33")) {
        change(0, 0, "agent_worker_b_w");
        move(0, -1);
        new(0, 1, "agent_ground_helper_red");
        set("@move_agent_b", "to", "@move_agent_b + 1");
        set("@x_b", "to", "@x_b - 1");
    }
    else if (next_to(">=", "1", "agent_ground_helper_red")) {
        make(0, 0, "method_2");
    }
}

```

```

public void neighbor_east() {
    if (see_a(0, 1, "agent_wall")) {
        make(0, 0, "method_1");
    }
}

```

```

    }
    else if (see(0, 1, "agent_ground")) {
        change(0, 0, "agent_worker_b_e");
        move(0, 1);
        new(0, -1, "agent_ground_helper_red");
        set("@move_agent_b", "to", "@move_agent_b + 1");
        set("@x_b", "to", "@x_b + 1");
    }
    else if (see(1, 0, "agent_ground") && %_chance("33")) {
        change(0, 0, "agent_worker_b_s");
        move(1, 0);
        new(-1, 0, "agent_ground_helper_red");
        set("@move_agent_b", "to", "@move_agent_b + 1");
        set("@y_b", "to", "@y_b - 1");
    }
    else if (see(0, -1, "agent_ground") && %_chance("33")) {
        change(0, 0, "agent_worker_b_w");
        move(0, -1);
        new(0, 1, "agent_ground_helper_red");
        set("@move_agent_b", "to", "@move_agent_b + 1");
        set("@x_b", "to", "@x_b - 1");
    }
    else if (see(-1, 0, "agent_ground") && %_chance("33")) {
        change(0, 0, "agent_worker_b");
        move(-1, 0);
        new(1, 0, "agent_ground_helper_red");
        set("@move_agent_b", "to", "@move_agent_b + 1");
        set("@y_b", "to", "@y_b + 1");
    }
    else if (next_to(">=", "1", "agent_ground_helper_red")) {
        make(0, 0, "method_2");
    }
}

public void neighbor_south() {
    if (see_a(1, 0, "agent_wall")) {
        make(0, 0, "method_1");
    }
    else if (see(1, 0, "agent_ground")) {
        change(0, 0, "agent_worker_b_s");
        move(1, 0);
        new(-1, 0, "agent_ground_helper_red");
        set("@move_agent_b", "to", "@move_agent_b + 1");
        set("@y_b", "to", "@y_b - 1");
    }
    else if (see(0, -1, "agent_ground") && %_chance("33")) {

```

```

        change(0, 0, "agent_worker_b_w");
        move(0, -1);
        new(0, 1, "agent_ground_helper_red");
        set("@move_agent_b", "to", "@move_agent_b + 1");
        set("@x_b", "to", "@x_b - 1");
    }
    else if (see(-1, 0, "agent_ground") && %_chance("33")) {
        change(0, 0, "agent_worker_b");
        move(-1, 0);
        new(1, 0, "agent_ground_helper_red");
        set("@move_agent_b", "to", "@move_agent_b + 1");
        set("@y_b", "to", "@y_b + 1");
    }
    else if (see(0, 1, "agent_ground") && %_chance("33")) {
        change(0, 0, "agent_worker_b_e");
        move(0, 1);
        new(0, -1, "agent_ground_helper_red");
        set("@move_agent_b", "to", "@move_agent_b + 1");
        set("@x_b", "to", "@x_b + 1");
    }
    else if (next_to(">=", "1", "agent_ground_helper_red")) {
        make(0, 0, "method_2");
    }
}

```

```

public void neighbor_west() {
    if (see_a(0, -1, "agent_wall")) {
        make(0, 0, "method_1");
    }
    else if (see(0, -1, "agent_ground")) {
        change(0, 0, "agent_worker_b_w");
        move(0, -1);
        new(0, 1, "agent_ground_helper_red");
        set("@move_agent_b", "to", "@move_agent_b + 1");
        set("@x_b", "to", "@x_b - 1");
    }
    else if (see(-1, 0, "agent_ground") && %_chance("33")) {
        change(0, 0, "agent_worker_b");
        move(-1, 0);
        new(1, 0, "agent_ground_helper_red");
        set("@move_agent_b", "to", "@move_agent_b + 1");
        set("@y_b", "to", "@y_b + 1");
    }
    else if (see(0, 1, "agent_ground") && %_chance("33")) {
        change(0, 0, "agent_worker_b_e");
        move(0, 1);
    }
}

```

```

        new(0, -1, "agent_ground_helper_red");
        set("@move_agent_b", "to", "@move_agent_b + 1");
        set("@x_b", "to", "@x_b + 1");
    }
    else if (see(1, 0, "agent_ground") && %_chance("33")) {
        change(0, 0, "agent_worker_b_s");
        move(1, 0);
        new(-1, 0, "agent_ground_helper_red");
        set("@move_agent_b", "to", "@move_agent_b + 1");
        set("@y_b", "to", "@y_b - 1");
    }
    else if (next_to(">=", "1", "agent_ground_helper_red")) {
        make(0, 0, "method_2");
    }
}

public void neighbor_north_revst() {
    if (see_a(-1, 0, "agent_wall")) {
        make(0, 0, "method_1");
    }
    else if (see(-1, 0, "agent_ground")) {
        change(0, 0, "agent_worker_b");
        move(-1, 0);
        new(1, 0, "agent_ground_helper_revst");
        set("@move_agent_b", "to", "@move_agent_b + 1");
        set("@y_b", "to", "@y_b + 1");
    }
    else if (see(0, 1, "agent_ground") && %_chance("33")) {
        change(0, 0, "agent_worker_b_e");
        move(0, 1);
        new(0, -1, "agent_ground_helper_revst");
        set("@move_agent_b", "to", "@move_agent_b + 1");
        set("@x_b", "to", "@x_b + 1");
    }
    else if (see(1, 0, "agent_ground") && %_chance("33")) {
        change(0, 0, "agent_worker_b_s");
        move(1, 0);
        new(-1, 0, "agent_ground_helper_revst");
        set("@move_agent_b", "to", "@move_agent_b + 1");
        set("@y_b", "to", "@y_b - 1");
    }
    else if (see(0, -1, "agent_ground") && %_chance("33")) {
        change(0, 0, "agent_worker_b_w");
        move(0, -1);
        new(0, 1, "agent_ground_helper_revst");
        set("@move_agent_b", "to", "@move_agent_b + 1");
    }
}

```

```

        set("@x_b", "to", "@x_b - 1");
    }
    else if (next_to(">=", "1", "agent_ground_helper_red")) {
        make(0, 0, "method_2");
    }
}

public void neighbor_east_revst() {
    if (see_a(0, 1, "agent_wall")) {
        make(0, 0, "method_1");
    }
    else if (see(0, 1, "agent_ground")) {
        change(0, 0, "agent_worker_b_e");
        move(0, 1);
        new(0, -1, "agent_ground_helper_revst");
        set("@move_agent_b", "to", "@move_agent_b + 1");
        set("@x_b", "to", "@x_b + 1");
    }
    else if (see(1, 0, "agent_ground") && %_chance("33")) {
        change(0, 0, "agent_worker_b_s");
        move(1, 0);
        new(-1, 0, "agent_ground_helper_revst");
        set("@move_agent_b", "to", "@move_agent_b + 1");
        set("@y_b", "to", "@y_b - 1");
    }
    else if (see(0, -1, "agent_ground") && %_chance("33")) {
        change(0, 0, "agent_worker_b_w");
        move(0, -1);
        new(0, 1, "agent_ground_helper_revst");
        set("@move_agent_b", "to", "@move_agent_b + 1");
        set("@x_b", "to", "@x_b - 1");
    }
    else if (see(-1, 0, "agent_ground") && %_chance("33")) {
        change(0, 0, "agent_worker_b");
        move(-1, 0);
        new(1, 0, "agent_ground_helper_revst");
        set("@move_agent_b", "to", "@move_agent_b + 1");
        set("@y_b", "to", "@y_b + 1");
    }
    else if (next_to(">=", "1", "agent_ground_helper_red")) {
        make(0, 0, "method_2");
    }
}

public void neighbor_south_revst() {
    if (see_a(1, 0, "agent_wall")) {

```

```

        make(0, 0, "method_1");
    }
    else if (see(1, 0, "agent_ground")) {
        change(0, 0, "agent_worker_b_s");
        move(1, 0);
        new(-1, 0, "agent_ground_helper_revst");
        set("@move_agent_b", "to", "@move_agent_b + 1");
        set("@y_b", "to", "@y_b - 1");
    }
    else if (see(0, -1, "agent_ground") && %_chance("33")) {
        change(0, 0, "agent_worker_b_w");
        move(0, -1);
        new(0, 1, "agent_ground_helper_revst");
        set("@move_agent_b", "to", "@move_agent_b + 1");
        set("@x_b", "to", "@x_b - 1");
    }
    else if (see(-1, 0, "agent_ground") && %_chance("33")) {
        change(0, 0, "agent_worker_b");
        move(-1, 0);
        new(1, 0, "agent_ground_helper_revst");
        set("@move_agent_b", "to", "@move_agent_b + 1");
        set("@y_b", "to", "@y_b + 1");
    }
    else if (see(0, 1, "agent_ground") && %_chance("33")) {
        change(0, 0, "agent_worker_b_e");
        move(0, 1);
        new(0, -1, "agent_ground_helper_revst");
        set("@move_agent_b", "to", "@move_agent_b + 1");
        set("@x_b", "to", "@x_b + 1");
    }
    else if (next_to(">=", "1", "agent_ground_helper_red")) {
        make(0, 0, "method_2");
    }
}

public void neighbor_west_revst() {
    if (see_a(0, -1, "agent_wall")) {
        make(0, 0, "method_1");
    }
    else if (see(0, -1, "agent_ground")) {
        change(0, 0, "agent_worker_b_w");
        move(0, -1);
        new(0, 1, "agent_ground_helper_revst");
        set("@move_agent_b", "to", "@move_agent_b + 1");
        set("@x_b", "to", "@x_b - 1");
    }
}

```

```

else if (see(-1, 0, "agent_ground") && %_chance("33")) {
    change(0, 0, "agent_worker_b");
    move(-1, 0);
    new(1, 0, "agent_ground_helper_revst");
    set("@move_agent_b", "to", "@move_agent_b + 1");
    set("@y_b", "to", "@y_b + 1");
}
else if (see(0, 1, "agent_ground") && %_chance("33")) {
    change(0, 0, "agent_worker_b_e");
    move(0, 1);
    new(0, -1, "agent_ground_helper_revst");
    set("@move_agent_b", "to", "@move_agent_b + 1");
    set("@x_b", "to", "@x_b + 1");
}
else if (see(1, 0, "agent_ground") && %_chance("33")) {
    change(0, 0, "agent_worker_b_s");
    move(1, 0);
    new(-1, 0, "agent_ground_helper_revst");
    set("@move_agent_b", "to", "@move_agent_b + 1");
    set("@y_b", "to", "@y_b - 1");
}
else if (next_to(">=", "1", "agent_ground_helper_red")) {
    make(0, 0, "method_2");
}
}

public void neighbor_north_east() {
    if (see_a(-1, 0, "agent_wall") && see_a(0, 1, "agent_wall")) {
        make(0, 0, "method_1");
    }
    else if (see(-1, 0, "agent_ground") && %_chance("50")) {
        change(0, 0, "agent_worker_b");
        move(-1, 0);
        new(1, 0, "agent_ground_helper_red");
        set("@move_agent_b", "to", "@move_agent_b + 1");
        set("@y_b", "to", "@y_b + 1");
    }
    else if (see(0, 1, "agent_ground") && %_chance("50")) {
        change(0, 0, "agent_worker_b_e");
        move(0, 1);
        new(0, -1, "agent_ground_helper_red");
        set("@move_agent_b", "to", "@move_agent_b + 1");
        set("@x_b", "to", "@x_b + 1");
    }
    else if (see_a(-1, 0, "agent_wall") && see(0, 1, "agent_ground_helper_red")) {
        make(0, 0, "method_1");
    }
}

```

```

    }
    else if (see_a(0, 1, "agent_wall") && see(-1, 0, "agent_ground_helper_red")) {
        make(0, 0, "method_1");
    }
    else if (see(-1, 0, "agent_ground_helper_red") && see(0, 1, "agent_ground_helper_red")) {
        make(0, 0, "method_2");
    }
    else if (next_to(">", "0", "agent_ground_helper_revst")) {
        make(0, 0, "method_2");
    }
}

```

```

public void neighbor_north_south() {
    if (see_a(-1, 0, "agent_wall") && see_a(1, 0, "agent_wall")) {
        make(0, 0, "method_1");
    }
    else if (see(-1, 0, "agent_ground") && %_chance("50")) {
        change(0, 0, "agent_worker_b");
        move(-1, 0);
        new(1, 0, "agent_ground_helper_red");
        set("@move_agent_b", "to", "@move_agent_b + 1");
        set("@y_b", "to", "@y_b + 1");
    }
    else if (see(1, 0, "agent_ground") && %_chance("50")) {
        change(0, 0, "agent_worker_b_s");
        move(1, 0);
        new(-1, 0, "agent_ground_helper_red");
        set("@move_agent_b", "to", "@move_agent_b + 1");
        set("@y_b", "to", "@y_b - 1");
    }
    else if (see_a(-1, 0, "agent_wall") && see(1, 0, "agent_ground_helper_red")) {
        make(0, 0, "method_1");
    }
    else if (see_a(1, 0, "agent_wall") && see(-1, 0, "agent_ground_helper_red")) {
        make(0, 0, "method_1");
    }
    else if (see(-1, 0, "agent_ground_helper_red") && see(1, 0, "agent_ground_helper_red")) {
        make(0, 0, "method_2");
    }
    else if (next_to(">", "0", "agent_ground_helper_revst")) {
        make(0, 0, "method_2");
    }
}

```

```

public void neighbor_north_west() {
    if (see_a(-1, 0, "agent_wall") && see_a(0, -1, "agent_wall")) {

```

```

        make(0, 0, "method_1");
    }
    else if (see(-1, 0, "agent_ground") && %_chance("50")) {
        change(0, 0, "agent_worker_b");
        move(-1, 0);
        new(1, 0, "agent_ground_helper_red");
        set("@move_agent_b", "to", "@move_agent_b + 1");
        set("@y_b", "to", "@y_b + 1");
    }
    else if (see(0, -1, "agent_ground") && %_chance("50")) {
        change(0, 0, "agent_worker_b_w");
        move(0, -1);
        new(0, 1, "agent_ground_helper_red");
        set("@move_agent_b", "to", "@move_agent_b + 1");
        set("@x_b", "to", "@x_b - 1");
    }
    else if (see_a(-1, 0, "agent_wall") && see(0, -1, "agent_ground_helper_red")) {
        make(0, 0, "method_1");
    }
    else if (see_a(0, -1, "agent_wall") && see(-1, 0, "agent_ground_helper_red")) {
        make(0, 0, "method_1");
    }
    else if (see(-1, 0, "agent_ground_helper_red") && see(0, -1, "agent_ground_helper_red")) {
        make(0, 0, "method_2");
    }
    else if (next_to(">", "0", "agent_ground_helper_revst")) {
        make(0, 0, "method_2");
    }
}

public void neighbor_east_south() {
    if (see_a(0, 1, "agent_wall") && see_a(1, 0, "agent_wall")) {
        make(0, 0, "method_1");
    }
    else if (see(0, 1, "agent_ground") && %_chance("50")) {
        change(0, 0, "agent_worker_b_e");
        move(0, 1);
        new(0, -1, "agent_ground_helper_red");
        set("@move_agent_b", "to", "@move_agent_b + 1");
        set("@x_b", "to", "@x_b + 1");
    }
    else if (see(1, 0, "agent_ground") && %_chance("50")) {
        change(0, 0, "agent_worker_b_s");
        move(1, 0);
        new(-1, 0, "agent_ground_helper_red");
        set("@move_agent_b", "to", "@move_agent_b + 1");
    }
}

```

```

        set("@y_b", "to", "@y_b - 1");
    }
    else if (see_a(0, 1, "agent_wall") && see(1, 0, "agent_ground_helper_red")) {
        make(0, 0, "method_1");
    }
    else if (see_a(1, 0, "agent_wall") && see(0, 1, "agent_ground_helper_red")) {
        make(0, 0, "method_1");
    }
    else if (see(0, 1, "agent_ground_helper_red") && see(1, 0, "agent_ground_helper_red")) {
        make(0, 0, "method_2");
    }
    else if (next_to(">", "0", "agent_ground_helper_revst")) {
        make(0, 0, "method_2");
    }
}

public void neighbor_east_west() {
    if (see_a(0, -1, "agent_wall") && see_a(0, 1, "agent_wall")) {
        make(0, 0, "method_1");
    }
    else if (see(0, -1, "agent_ground") && %_chance("50")) {
        change(0, 0, "agent_worker_b_w");
        move(0, -1);
        new(0, 1, "agent_ground_helper_red");
        set("@move_agent_b", "to", "@move_agent_b + 1");
        set("@x_b", "to", "@x_b - 1");
    }
    else if (see(0, 1, "agent_ground") && %_chance("50")) {
        change(0, 0, "agent_worker_b_e");
        move(0, 1);
        new(0, -1, "agent_ground_helper_red");
        set("@move_agent_b", "to", "@move_agent_b + 1");
        set("@x_b", "to", "@x_b + 1");
    }
    else if (see_a(0, -1, "agent_wall") && see(0, 1, "agent_ground_helper_red")) {
        make(0, 0, "method_1");
    }
    else if (see_a(0, 1, "agent_wall") && see(0, -1, "agent_ground_helper_red")) {
        make(0, 0, "method_1");
    }
    else if (see(0, -1, "agent_ground_helper_red") && see(0, 1, "agent_ground_helper_red")) {
        make(0, 0, "method_2");
    }
    else if (next_to(">", "0", "agent_ground_helper_revst")) {
        make(0, 0, "method_2");
    }
}

```

```

}

public void neighbor_south_west() {
    if (see_a(1, 0, "agent_wall") && see_a(0, -1, "agent_wall")) {
        make(0, 0, "method_1");
    }
    else if (see(1, 0, "agent_ground") && %_chance("50")) {
        change(0, 0, "agent_worker_b_s");
        move(1, 0);
        new(-1, 0, "agent_ground_helper_red");
        set("@move_agent_b", "to", "@move_agent_b + 1");
        set("@y_b", "to", "@y_b - 1");
    }
    else if (see(0, -1, "agent_ground") && %_chance("50")) {
        change(0, 0, "agent_worker_b_w");
        move(0, -1);
        new(0, 1, "agent_ground_helper_red");
        set("@move_agent_b", "to", "@move_agent_b + 1");
        set("@x_b", "to", "@x_b - 1");
    }
    else if (see_a(1, 0, "agent_wall") && see(0, -1, "agent_ground_helper_red")) {
        make(0, 0, "method_1");
    }
    else if (see_a(0, -1, "agent_wall") && see(1, 0, "agent_ground_helper_red")) {
        make(0, 0, "method_1");
    }
    else if (see(1, 0, "agent_ground_helper_red") && see(0, -1, "agent_ground_helper_red")) {
        make(0, 0, "method_2");
    }
    else if (next_to(">", "0", "agent_ground_helper_revst")) {
        make(0, 0, "method_2");
    }
}

public void neighbor_east_south_west() {
    if (see(0, 1, "agent_ground") && %_chance("33")) {
        make(0, 0, "neighbor_east");
    }
    else if (see(1, 0, "agent_ground") && %_chance("33")) {
        make(0, 0, "neighbor_south");
    }
    else if (see(0, -1, "agent_ground") && %_chance("33")) {
        make(0, 0, "neighbor_west");
    }
    else if (see(0, 1, "agent_ground_helper_red") && see(1, 0, "agent_ground_helper_red") &&
see(0, -1, "agent_ground_helper_red")) {

```

```

        make(0, 0, "method_2");
    }
    else if (true) {
        make(0, 0, "method_2");
    }
}

public void neighbor_south_west_north() {
    if (see(1, 0, "agent_ground") && %_chance("33")) {
        make(0, 0, "neighbor_south");
    }
    else if (see(0, -1, "agent_ground") && %_chance("33")) {
        make(0, 0, "neighbor_west");
    }
    else if (see(-1, 0, "agent_ground") && %_chance("33")) {
        make(0, 0, "neighbor_north");
    }
    else if (see(1, 0, "agent_ground_helper_red") && see(0, -1, "agent_ground_helper_red")
&& see(-1, 0, "agent_ground_helper_red")) {
        make(0, 0, "method_2");
    }
    else if (true) {
        make(0, 0, "method_2");
    }
}

public void neighbor_west_north_east() {
    if (see(0, -1, "agent_ground") && %_chance("33")) {
        make(0, 0, "neighbor_west");
    }
    else if (see(-1, 0, "agent_ground") && %_chance("33")) {
        make(0, 0, "neighbor_north");
    }
    else if (see(0, 1, "agent_ground") && %_chance("33")) {
        make(0, 0, "neighbor_east");
    }
    else if (see(0, -1, "agent_ground_helper_red") && see(-1, 0, "agent_ground_helper_red")
&& see(0, 1, "agent_ground_helper_red")) {
        make(0, 0, "method_2");
    }
    else if (true) {
        make(0, 0, "method_2");
    }
}

public void neighbor_north_east_south() {

```

```

    if (see(-1, 0, "agent_ground") && %_chance("33")) {
        make(0, 0, "neighbor_north");
    }
    else if (see(0, 1, "agent_ground") && %_chance("33")) {
        make(0, 0, "neighbor_east");
    }
    else if (see(1, 0, "agent_ground") && %_chance("33")) {
        make(0, 0, "neighbor_south");
    }
    else if (see(-1, 0, "agent_ground_helper_red") && see(0, 1, "agent_ground_helper_red")
&& see(1, 0, "agent_ground_helper_red")) {
        make(0, 0, "method_2");
    }
    else if (true) {
        make(0, 0, "method_2");
    }
}

public void destination() {
    if (see(-1, 0, "agent_destination")) {
        change(0, 0, "agent_worker_b");
        wait("0.15");
        move(-1, 0);
        new(1, 0, "agent_ground_helper_red");
        change(0, 0, "agent_destination_red");
        set("@y_b", "to", "@y_b + 1");
        wait("1");
        broadcast("agent_ground", "method_20");
        wait("1");
        broadcast("agent_destination", "method_10");
        wait("1");
        erase(0, 0);
    }
    else if (see(0, 1, "agent_destination")) {
        change(0, 0, "agent_worker_b_e");
        wait("0.15");
        move(0, 1);
        new(0, -1, "agent_ground_helper_red");
        change(0, 0, "agent_destination_red");
        set("@x_b", "to", "@x_b + 1");
        wait("1");
        broadcast("agent_ground", "method_20");
        wait("1");
        broadcast("agent_destination", "method_10");
        wait("1");
        erase(0, 0);
    }
}

```

```

    }
    else if (see(1, 0, "agent_destination")) {
        change(0, 0, "agent_worker_b_s");
        wait("0.15");
        move(1, 0);
        new(-1, 0, "agent_ground_helper_red");
        change(0, 0, "agent_destination_red");
        set("@y_b", "to", "@y_b - 1");
        wait("1");
        broadcast("agent_ground", "method_20");
        wait("1");
        broadcast("agent_destination", "method_10");
        wait("1");
        erase(0, 0);
    }
    else if (see(0, -1, "agent_destination")) {
        change(0, 0, "agent_worker_b_w");
        wait("0.15");
        move(0, -1);
        new(0, 1, "agent_ground_helper_red");
        change(0, 0, "agent_destination_red");
        set("@x_b", "to", "@x_b - 1");
        wait("1");
        broadcast("agent_ground", "method_20");
        wait("1");
        broadcast("agent_destination", "method_10");
        wait("1");
        erase(0, 0);
    }
    }
    else if (see(-1, 1, "agent_destination")) {
        make(0, 0, "method_0");
    }
    }
    else if (see(1, 1, "agent_destination")) {
        make(0, 0, "method_0");
    }
    }
    else if (see(1, -1, "agent_destination")) {
        make(0, 0, "method_0");
    }
    }
    else if (see(-1, -1, "agent_destination")) {
        make(0, 0, "method_0");
    }
    }
}
}

```

Environment A_1

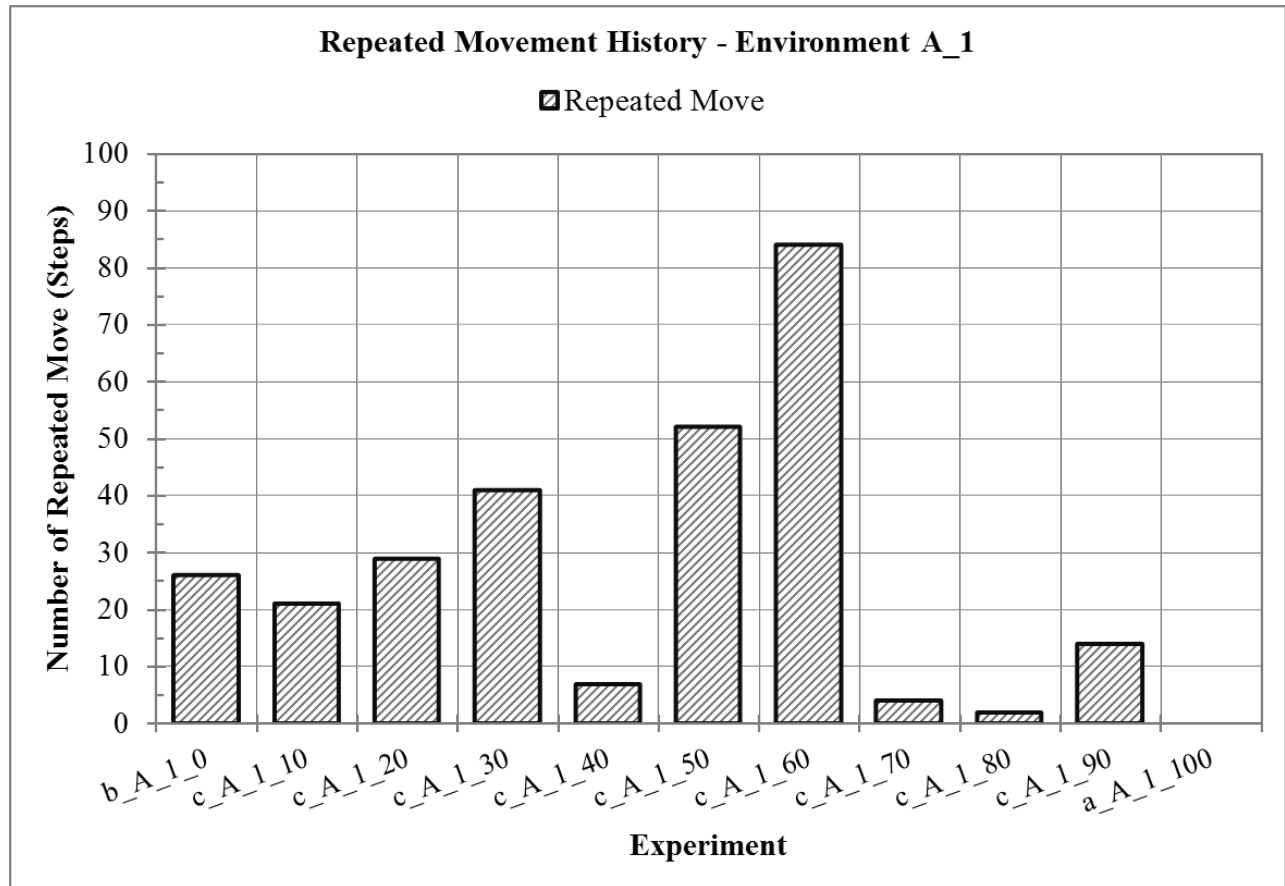


Figure A. 1– Repeated Movement History – Environment A_1

Environment A_2

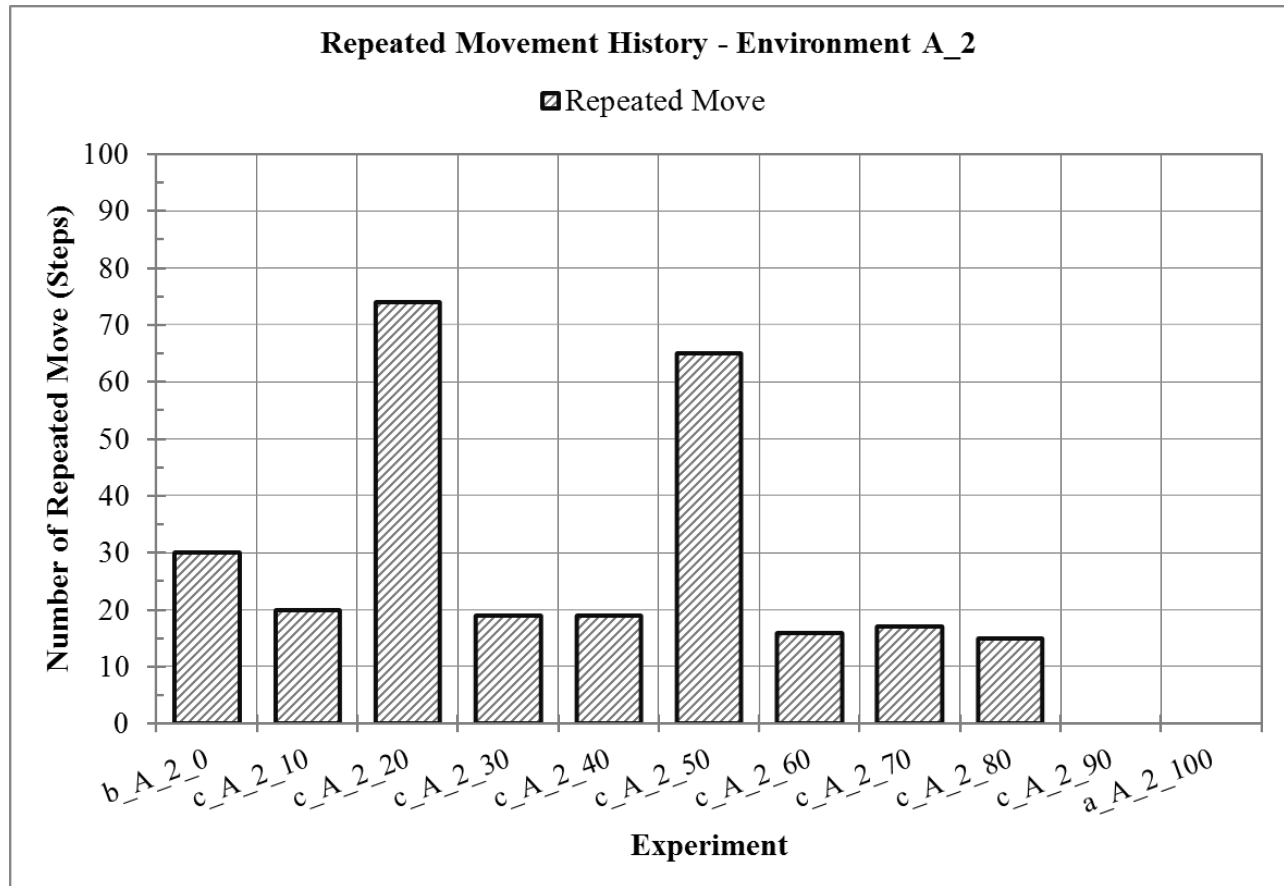


Figure A. 2 – Repeated Movement History – Environment A_2

Environment A_3

Table A. 1 – Summary of Outcomes for Environment A_3

Experiment Identification	Instruction Level (%)	Number of Repetitions	Movement History (Steps)		
			Minimum	<i>Average</i>	Maximum
b_A_3_0	0	50	31	35	47
c_A_3_10	10	50	31	36	53
c_A_3_20	20	50	31	36	47
c_A_3_30	30	50	31	32	47
c_A_3_40	40	50	31	34	43
c_A_3_50	50	50	31	41	101
c_A_3_60	60	50	31	35	45
c_A_3_70	70	50	31	35	51
c_A_3_80	80	50	31	32	39
c_A_3_90	90	50	31	32	51
a_A_3_100	100	1	31	31	31

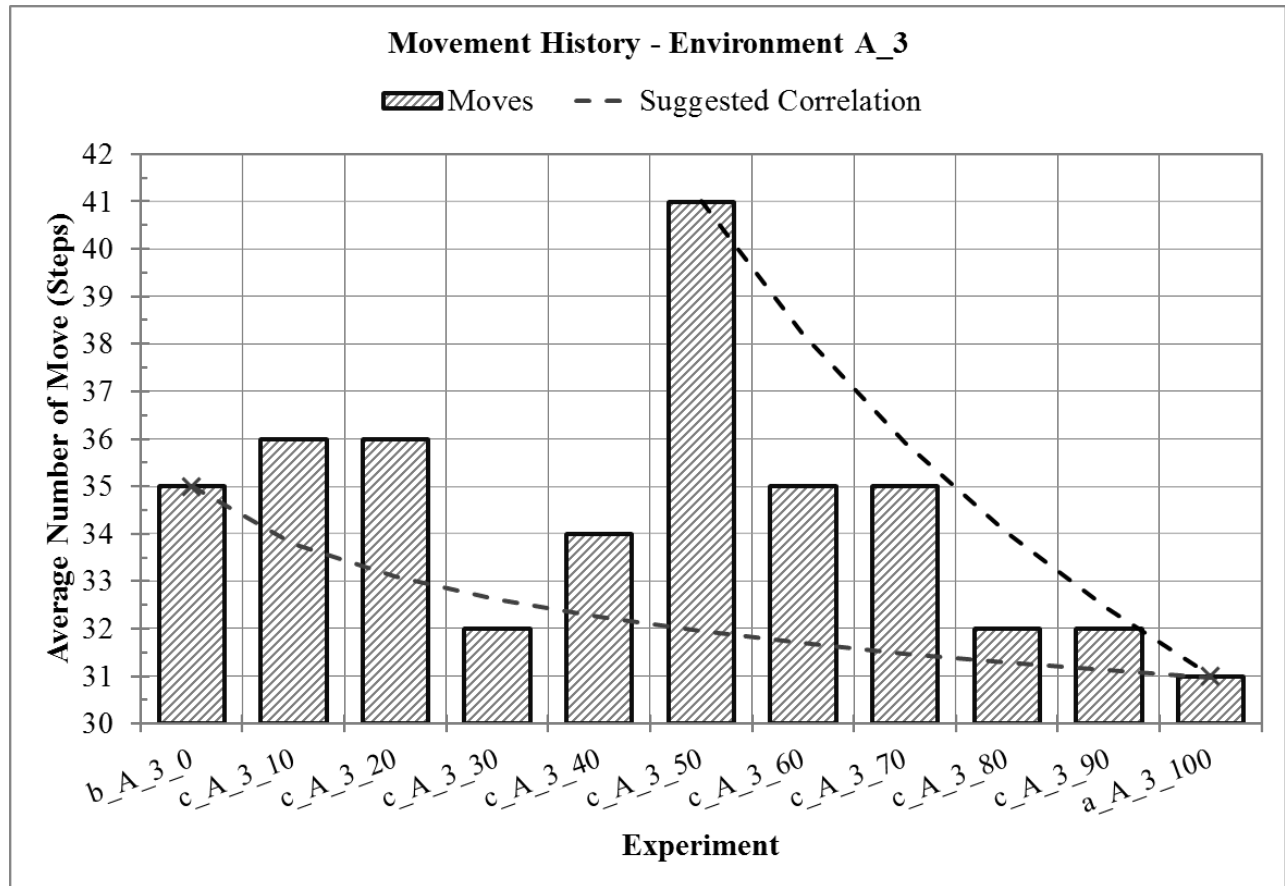


Figure A. 3 – Suggested Correlation amongst Effectiveness and Instruction – Environment A_3

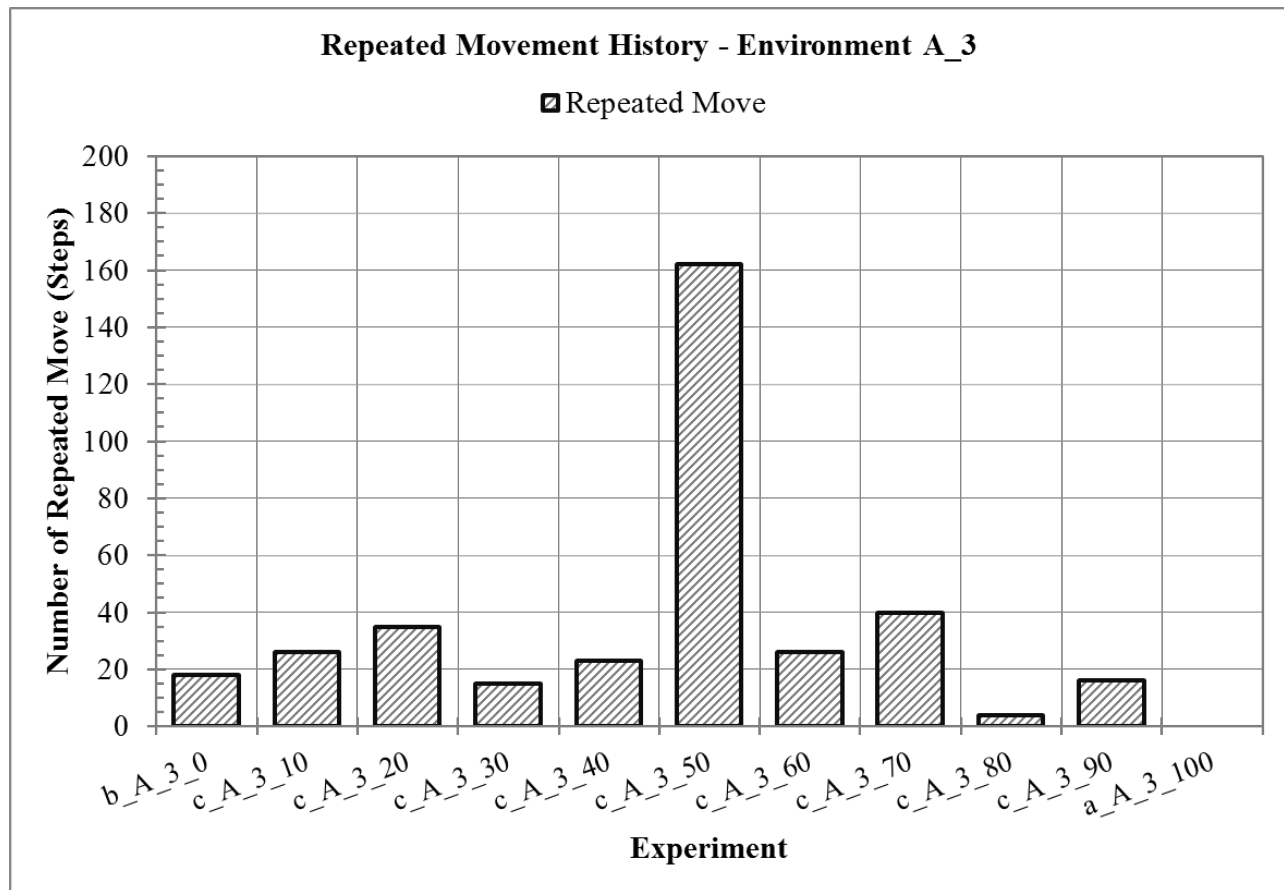


Figure A. 4 – Repeated Movement History – Environment A_3

Table A. 2 – Summary of Outcomes for Environment A_4

Experiment Identification	Instruction Level (%)	Number of Repetitions	Movement History (Steps)		
			Minimum	<i>Average</i>	Maximum
b_A_4_0	0	50	31	36	49
c_A_4_10	10	50	31	35	45
c_A_4_20	20	50	31	37	61
c_A_4_30	30	50	31	39	71
c_A_4_40	40	50	31	36	51
c_A_4_50	50	50	31	39	63
c_A_4_60	60	50	31	32	43
c_A_4_70	70	50	31	31	33
c_A_4_80	80	50	31	37	61
c_A_4_90	90	50	31	32	43
a_A_4_100	100	1	31	31	31

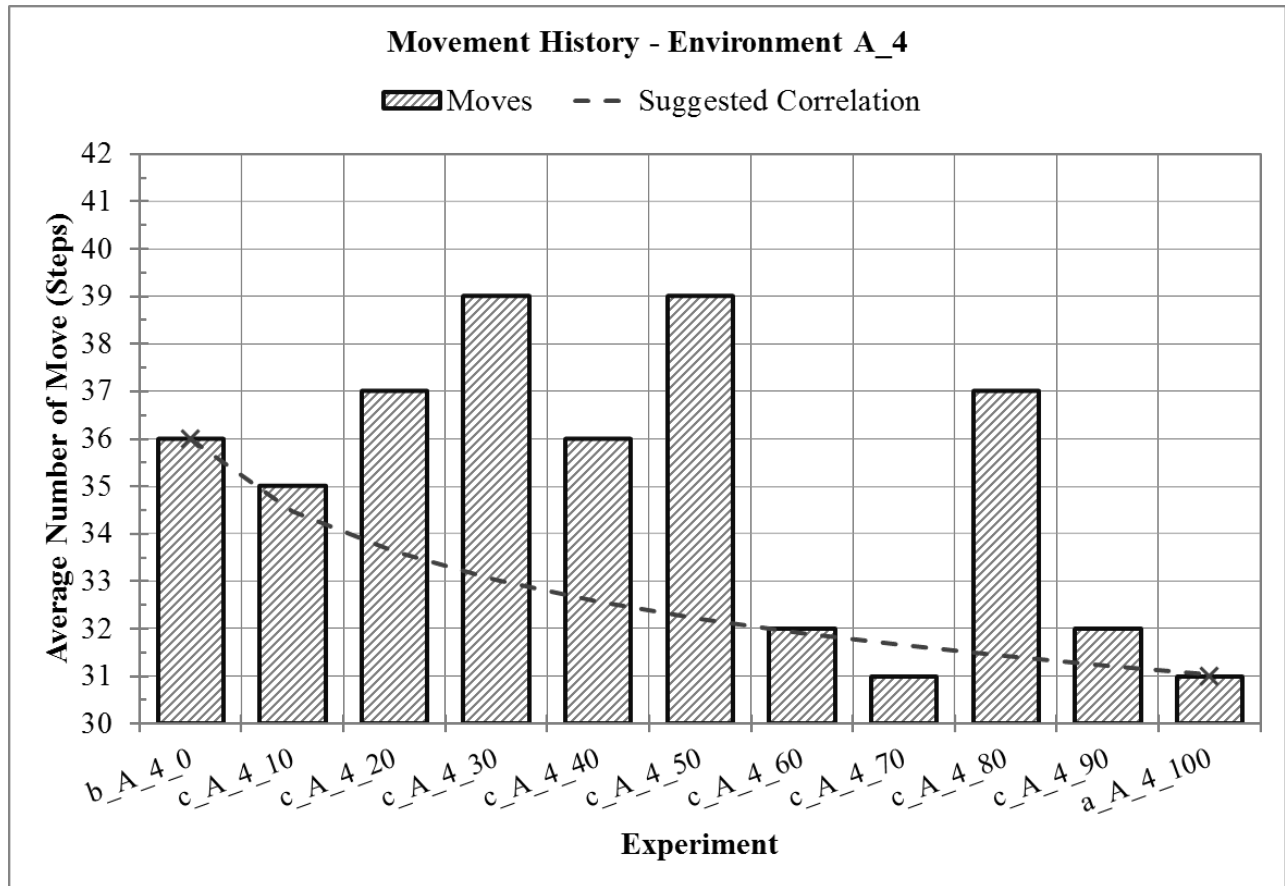


Figure A. 5 – Suggested Correlation amongst Effectiveness and Instruction – Environment A_4

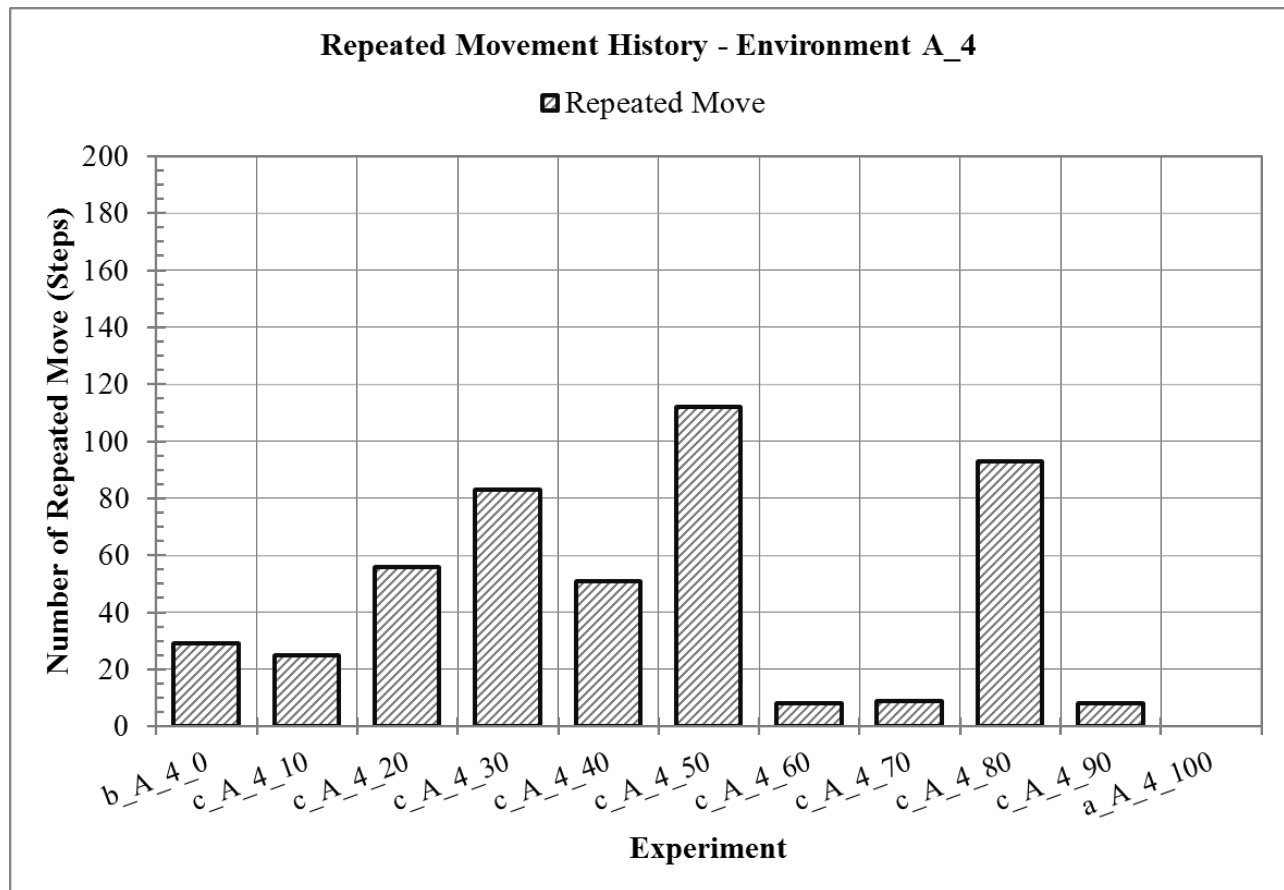


Figure A. 6 – Repeated Movement History – Environment A_4

Environment B_1

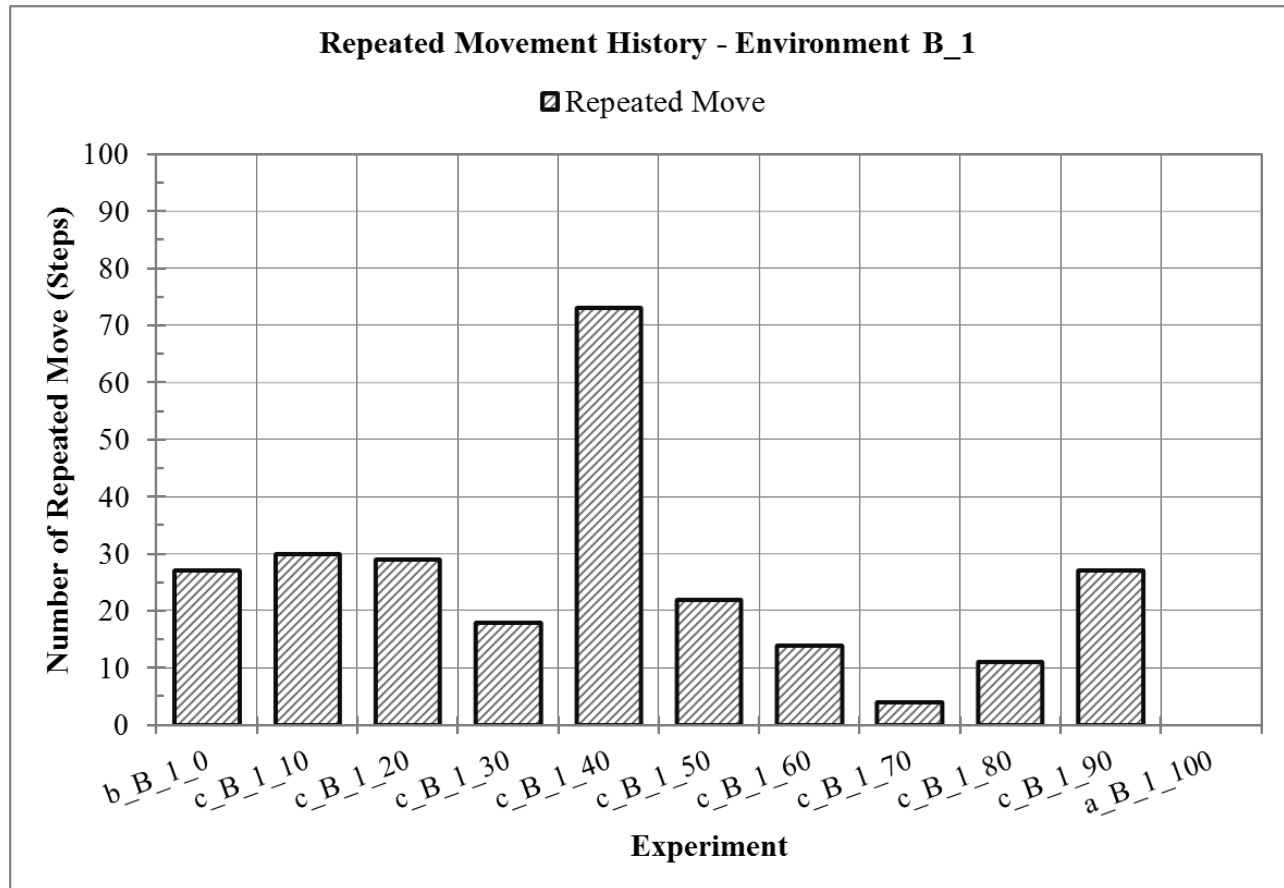


Figure A. 7 – Repeated Movement History – Environment B_1

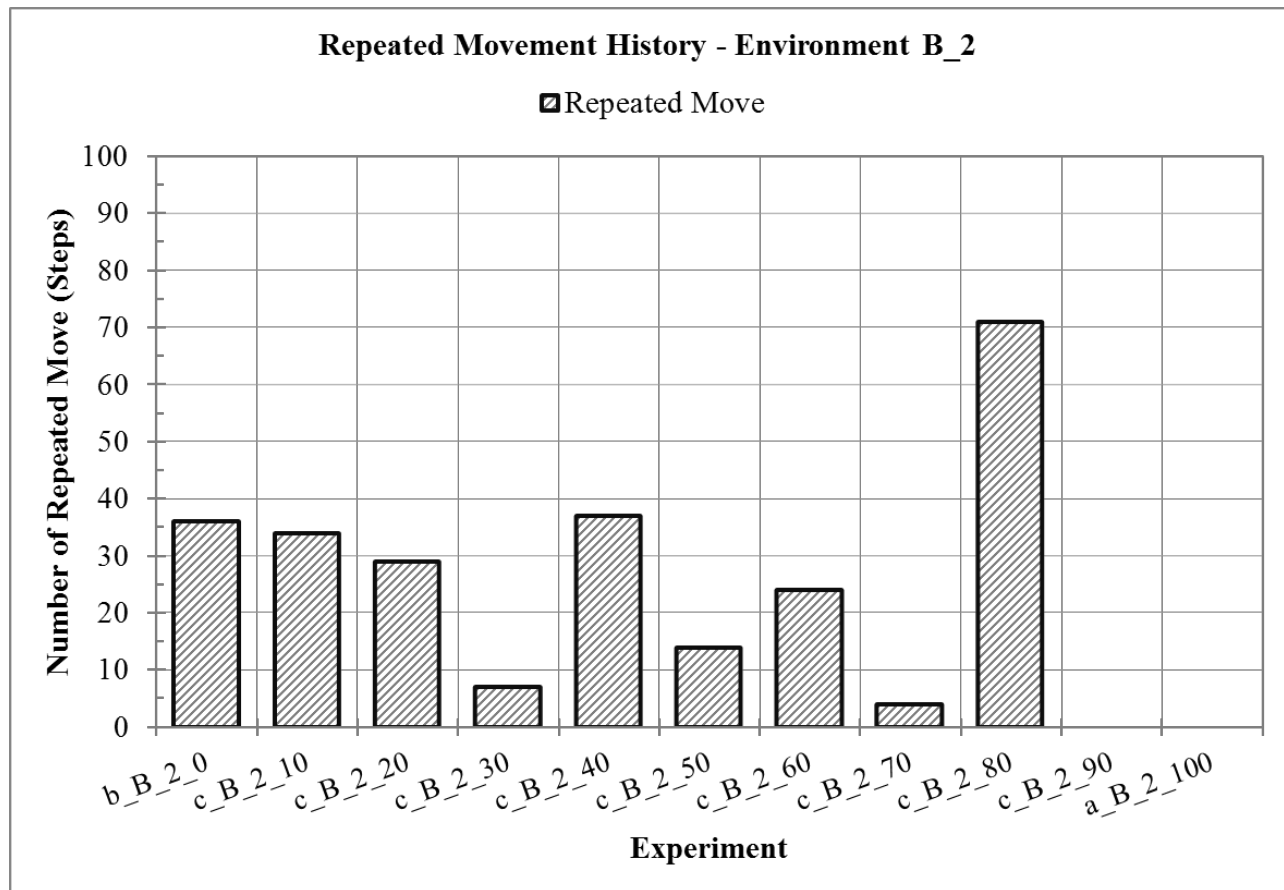


Figure A. 8 – Repeated Movement History – Environment B_2

Environment B_K

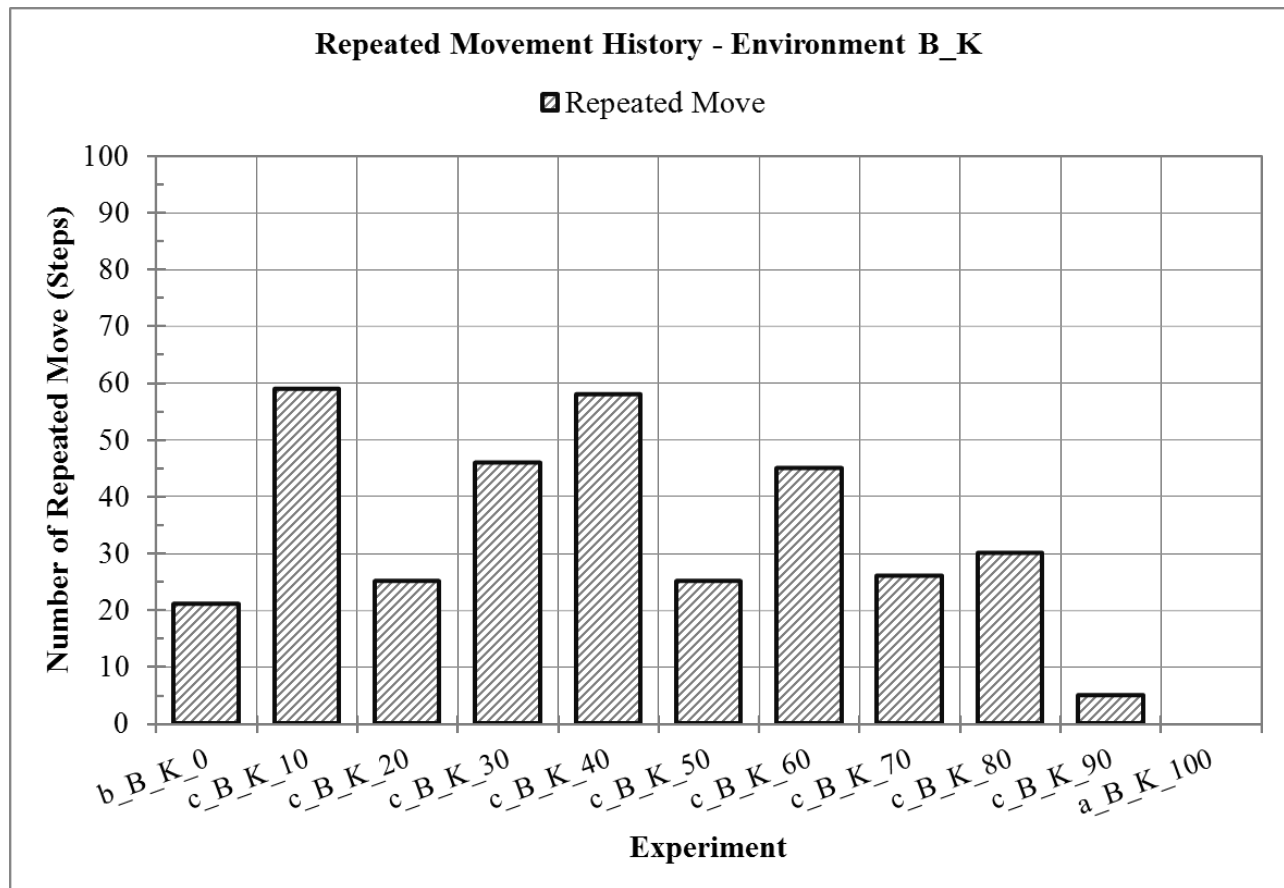


Figure A. 9 – Repeated Movement History – Environment B_K

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