

A Study on the Influence of Construction Workers' Physiological Status and Jobsite Environment on Behavior and Performance

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Understanding processes affecting workforce behavior and performance in terms of productivity, safety, and quality is of central importance to the social and economic sustainability of the construction industry. Existing theories stress the role of worker behavior in determining performance (e.g., accident causation theories), and identify several factors influencing behavior and performance. However, most of these theories are limited in scope and often tend to be confined within one discipline neglecting factors beyond the discipline's domain. Also, models often comprise relationships based on anecdotal evidence or heuristic approaches that are not fully clarified. Moreover, previous research studies on workers never analyzed the role played by worker's physiological status and jobsite physical, ergonomic and environmental stressors on behavior and performance. By building on existing knowledge, the long-term objective of the authors is to generate an effective and comprehensive behavior-performance model. The first step taken by the authors to accomplish this long-term objective focuses on generating an experimental program to model the relationship between worker productivity, safety, and quality behavior and performance, and the influence of worker's physiological status and jobsite physical environmental stressors on behavior and performance. The aim of this paper is to describe the experimental program research plan.

Key Words: Construction Management, Productivity, Quality, Occupational Health and Safety, Work Physiology

Introduction

Despite the numerous suggested tangible (e.g., cost) and intangible (e.g., satisfaction within team members) construction project performance indicators, time, cost, quality, and safety are usually agreed upon as the most important. Generally, given a specific project, time can be based on the project duration; cost on the project financial expenditure; quality on the project conformity to plans and specifications; and, safety on the amount and significance of accident, damages, and injuries occurred during the project. These key performance indicators are defined at project level and, therefore, they may not be meaningful at worker level. In particular, while safety and quality can be assessed at project and worker level, cost and time are generally meaningless at worker level. Nevertheless, researchers suggested that workforce productivity can be implemented as combined measure of cost and time (Jenkins & Orth, 2004). Therefore, it can be concluded that workforce productivity, quality, and safety are the most important performance indicators at worker level. However, the construction industry is still striving to improve the performance in these areas. For instance, the American Society of Civil Engineers (Brilakis et al., 2011) recently stated that improving construction productivity and enhancing construction site safety are still among the grand challenges for data sensing and analysis.

Previous studies proposed numerous models and theories stressing the role of worker behavior (i.e., how a worker perform during an activity/process) in determining performance (i.e., given a certain input, the amount of output produced by a worker during an activity/process), and listed several factors influencing behavior and performance. However, most of the proposed models and theories are limited in scope and/or effectiveness. For instance, these models tend to be confined within one discipline and, therefore, neglect factors beyond the discipline's domain. Then, many models comprise relationships based on anecdotal evidence or heuristic approaches. Moreover, previous research studies focusing on construction rarely analyzed the role played by worker's physiological status (i.e., the set of physiological parameters capable of characterize the human metabolism, such as heart rate, oxygen consumption, and body temperature) and jobsite physical environmental stressors (i.e., physical factors capable of affecting the human metabolism, such as air temperature, air humidity, airflow and ventilation, vibration, lightning, noise, liquid exposure) on behavior and performance. Hence, an effective and comprehensive model that clearly establishes the relationships between behavior and performance for construction productivity, safety, and quality while evaluating the role played by the numerous influencing factors has yet to be established. Therefore, by building on existing knowledge in several areas, such as Industrial and Construction Engineering, Ergonomics, Work Physiology, and Occupational Safety and Health, the long-term objective of the authors is to generate an effective and comprehensive behavior-performance model. The model will eventually improve construction productivity, safety, and quality management by clarifying mechanisms and factors that foster productivity, quality, and well-being and prevent accidents and injuries. Application examples of the model are: optimization of workflow and work break schedule at individual and crew level; reduction of exposure to excessive strain; optimization of personnel selection and worker – activity matching; and, development of more effective training course, procedures, rules, and regulations. The first step taken by the authors to accomplish this long-term and wide-raging objective focuses on generating an integrated theoretical and experimental program to model (1) the relationship between worker productivity, safety, and quality behavior and performance, and (2) the influence of worker's physiological status and jobsite physical environmental stressors on behavior and performance. The aim of this paper is to describe the theoretical and experimental program. First, the reviewed existing knowledge is discussed. Then, the objectives of the experimental program are presented. Finally, the designed research procedure and activities are described.

State of Knowledge

This section discusses concepts, theories, and models from numerous disciplines, and provides the theoretical grounding for the proposed model. First, the constructs of construction workforce performance and behavior are presented. Second, the workforce behavior-performance relationship is discussed. Finally, previous studies on the topic performed by the authors are briefly presented.

Construction Workforce Behavior and Performance

It is widely acknowledged that behavior and performance are related. However, the literature presents several meanings for behavior and performance because the nature of the definitions is generally biased by authors´ field of knowledge and interest in these concepts. Therefore, before proceeding further, the constructs of workforce behavior and performance must be clearly defined. The following paragraphs discuss the definition of workforce behavior and performance adopted in this paper and the methods and techniques available to measure such constructs.

Given an activity or process accomplished by one or more workers, behavior is defined as *how the workers perform during the activity/process*, and performance is defined as *the ratio between two or more performance indicators*. In particular, the performance indicators are the inputs and the outputs of the activity/process. In other words, the measure of performance is based on what is needed (i.e., inputs) and produced (i.e., outputs) by the activity/process, while the measure of behavior is based on how workers employ the inputs to obtain the outputs. Therefore, although both performance and behavior characterize the activity/process, the difference between the two constructs is substantial.

According to the previous definition, a set of indicators (i.e., inputs and outputs) is necessary to define a specific performance. It is acknowledged in construction that productivity performance measures production efficiency; safety performance measures how safe the working environment is; and, assuming that the designers correctly captured owner and user expectations, quality performance measures the conformity to plan and specifications. However, no general agreement has been established regarding standard indicators as well as standard measurement techniques of productivity, safety, and quality performances. Therefore, such indicators have to be established on project-by-project basis. Few examples of common construction productivity, safety, and quality performance indicators and performance definitions are shown in Table 1.

Table 1

Examples of common inputs and outputs employed to measure productivity, safety, and quality performance

Performance	Input: Quantity or Monetary Value of	Output: Quantity or Monetary Value of	Examples of Actual Definitions
Productivity	labor, unit of completed work, capital, material, equipment, & energy	hours, man-hours, workers, & unit of completed work	average labor productivity, single factor productivity, multi factor productivity, & total factor productivity
Safety	accidents, injuries, days away of work, near misses, & damages		OSHA injury/illness incidence Rates, & Experience Modification Rating (EMR)
Quality	rework, wastages, defects, claims, & disputes		ISO 9000, Six Sigma, & Total Quality Management (TQM) measuring and monitoring methods

Numerous productivity behavior assessment methods and techniques are available in the construction and manufacturing literature. Broadly, productivity behavior assessment methods are employed to achieve an effective and efficient management of activities through the enhancement of equipment efficiency and workforce utilization. Three types of behavior assessment methods have been largely used in construction: activity/work sampling; time studies; and, questionnaires and interviews (Oglesby, Parker, & Howell, 1989). Despite the fact that workforce safety behavior is recognized as a crucial element in causing accident and injuries (Goetsch, 2010; Lund & Aarø, 2004), most of the literature about workforce behavior paid more attention to the analysis and measure of productivity behavior rather than safety behavior. Therefore, safety behavior assessment methods and techniques are rare. Nevertheless, a technique called safety sampling proved to be dependable in the construction industry (Shohet & Laufer, 1991). This technique was developed from the work/activity sampling technique and, therefore, it presents a similar methodology in categorizing the workforce behaviors. For example, Shohet and Laufer (1991) proposed the following categorization for safety behaviors: safe behavior, “the worker performs his job without risk of hazard to himself or others, and his surroundings are considered safe” (p. 572); and, unsafe behavior, “the hazardous use of tools or equipment, the hasty execution of work in an unsafe place or under unsafe conditions” (p. 573). To the best of the authors’ knowledge, workforce quality behavior has not been investigated in previous studies. Nevertheless, as work/activity sampling was adapted to assess safety behaviors, it can also be adapted to assess quality behaviors. For example, the categorization for quality behaviors could be: “correct behavior”, the worker follows plans and specifications while performing an activity; and, “incorrect behavior”, the worker does not follow plans and specifications while performing an activity. As for performance indicators, behavior categorization has to be established on project-by-project basis.

Workforce Behavior-Performance Relationship

Researches from various disciplines analyzed behavior, performance, and the influencing factors. The most significant concepts, models, and theories for this research are: the safety behavior-performance relationship and the influencing factors determined in the accident causation theories; the processes and factors affecting behavior proposed in the behavioral change theories; the influence of work demands on performance and behavior; and the factors influencing workforce performance and behavior discussed by Construction Management and Engineering researchers. These concepts, models, and theories are briefly presented and discussed in the following paragraphs.

Accident causation theories try to explain the underlying mechanisms of an accident. Some of the simpler models describe accidents as the product of a sequence of unfortunate events (Hollnagel, 2002). Although these theories deal with accidents and injuries, the proposed concepts can be also beneficial in understanding productivity and quality performance. Although numerous accident causation theories have been proposed, workforce unsafe behavior (e.g., mistakes in applying safety best practices) is among the most frequently cited factors causing accidents and injuries (Goetsch, 2010). Accident causation theories accounting for the role played by human behavior in causing accidents and injuries include: the accident/incident theory (Goetsch, 2010); the Rasmussen's descriptive model of work behavior (Rasmussen, Pejtersen, & Goodstein, 1994); and, the Lund and Aarø's accident prevention model (Lund & Aarø, 2004).

Behavioral change theories aim to explain processes generating alterations in individuals' behavioral patterns. Numerous behavioral change theories have been proposed and applied across a wide variety of fields, such as communication, marketing, healthcare, education, transportation, energy consumption, finance, and criminology. Allport in 1935 presented one of the first and simplest behavioral change theories. This theory, known as the knowledge, attitude, and behavior model, states that knowledge about a behavior generates an attitude. This attitude, in turn, leads to a behavior in accordance with the attitude (Bettinghaus, 1986). However, researches identified several issues regarding this model. Thus, more advanced and complex theories were proposed, including the learning/social cognitive theory; and, the theory of reasoned action/planned behavior.

Excessive work demand has often been cited as detrimental for workforce behavior and performance (Abdelhamid & Everett, 2002; Astrand, Rodahl, Dahl, & Stromme, 2003; Oglesby et al., 1989). Abdelhamid and Everett (2002) stated that "physically demanding work can lead to physical fatigue, which may lead to decreased productivity and motivation, inattentiveness, poor judgment, poor quality work, job dissatisfaction, accident and injuries" (p. 427). The human body meets mental and manual work demands by activating specific metabolic and physiological reactions (e.g., changes in heart and oxygen consumption rate). Nevertheless, human body's capacity of adaptation is limited. Therefore, work performance and behavior are likely to change when a worker's physiological limits are reached or, in other words, when the worker is undergoing fatigue.

Countless performance and behavior influencing factors are listed in the literature. For instance, the most common factors affecting construction labor productivity (Oglesby et al., 1989; Thomas et al., 1990), safety (Haslam et al., 2005; Hide et al., 2003), and quality (Arditi & Gunaydin, 1997) were identified in previous studies and include (a) proper work planning, management, direction, supervision, or coordination; (b) adequacy of plans and specifications; (c) constructability; (d) construction methods, tools, and equipment; (d) satisfactory workforce supervision, education, and training; (e) environmental conditions; and, (f) workforce physical fatigue and health. Moreover, poor safety and quality performance (e.g., accidents and rework) are also detrimental to productivity performance. The literature review identified additional examples of factors influencing construction workforce behavior and performance that are listed in Table 2.

Table 2

Examples of performance and behavior influencing factors of relevance to construction

Factor Type	Example
Individual (i.e., factors related with worker's individual characteristics)	demographic factors (e.g., age, gender, ethnicity); cognitive factors (e.g., memory, attention, vigilance, reaction time); physiological status (e.g., heart rate, oxygen consumption, body temperature); physical and biomechanical attributes (e.g., body size, strength, force, speed);
Socio-cultural (i.e., factors related with worker's socio-cultural background)	social/family pressure; culture; religion; financial situation; family/relationship situation
Environmental (i.e., factors related with the environmental working conditions)	temperature; humidity; airflow and ventilation; vibration; lightning; noise; liquid exposure
Task (i.e., factors related with the features of the task performed by the worker)	production pressure; construction methods, tools, and equipment; clarity of plans and specifications; work schedule; workflow;
Teamwork (i.e., factors related with teamwork practices and processes of the worker's crew)	verbal and nonverbal interpersonal communication; teamwork skills and capabilities (e.g., leadership/followership, situation awareness); teamwork competences/processes (e.g., conflict and conflict resolution)
Organizational (i.e., factors related with worker's company culture and practices)	workforce education and training; culture, climate, policies, and procedures; planning, management, supervision, and coordination

Many of the presented models, theories, and concepts are limitedly effective for explaining performance issues in construction workforce. First, most of the proposed models and theories have not been operationalized or empirically validated in construction. “No valid theoretical framework exists to explain and predict worker motivation and performance in the construction industry” (Maloney & McFillen, 1983, p. 245). This concept was stated in 1983 and it still holds true. These models and theories are generally based on anecdotal evidence and/or heuristic approaches (Lund & Aarø, 2004) and, therefore, the validity of the proposed relationships is uncertain. Second, numerous models take into account only a small portion of the possible influencing factors capable of affecting workforce behavior and performance (Lund & Aarø, 2004; Maloney, 1984). Third, many applied models focus on aspects of performance and factors not directly applicable to the construction industry. Moreover, previous research efforts in construction did not analyze the role played by worker’s physiological status and jobsite physical environmental stressors on behavior and performance.

Previous Studies Performed by the Authors

To explain the role played by physiological status on behavior and performance, the authors have performed a series of preparatory studies. An initial study aimed at evaluating lab and field measurement techniques by establishing the validity of portable physiological monitoring devices in assessing worker physiological status during dynamic activities (Gatti, Migliaccio, & Schneider, n.d.). Similarly, the authors worked with colleagues in other disciplines to develop novel data fusion techniques to automatically detect unsafe behaviors (Cheng, Migliaccio, Teizer, & Gatti, 2012) and perform automatic task analysis (Cheng, Teizer, Migliaccio, & Gatti, 2012). These studies used lab experiments to collect data from workers’ physiological status, posture and position and developed measurement techniques to assess the worker physiological status – productivity (Cheng, Teizer, et al., 2012), and the worker physiological status – safety behavior (Cheng, Migliaccio, et al., 2012; Gatti, Migliaccio, Bogus, Priyadarshini, & Scharrer, 2012) relationships for simulated construction tasks. Also, an initial effort was made to evaluate the worker physiological status – productivity performance (Gatti, Migliaccio, Bogus, & Schneider, n.d.).

Objectives

The main goal of the experimental program is to evaluate and explain the role of worker’s physiological status and jobsite environment on behavior and performance in order to improve safety, quality and productivity performance. This goal is realized by achieving the following main research objectives:

1. Develop a general construction-based productivity, safety, and quality behavior-performance model that takes into consideration the role of worker’s physiological status and jobsite environment factors;
2. Identify an approach for tailoring this general model to specific tasks and work contexts by identifying appropriate influencing factors;
3. Identify existing methods and/or establish new approaches for measuring productivity and safety, behavior and performance, worker’s physiological status, and jobsite environment factors;
4. Test and improve the proposed behavior-performance model using the data collected in the lab activities; and,
5. Validate the tested behavior-performance model using the data collected in the field activities.

Procedure

A comprehensive research plan that includes several data collection instruments (e.g., interview guides and survey questionnaires, direct observation, wearable biosensors) will be utilized to obtain a comprehensive assessment of the model. To have a complete control over the influencing factors, lab experiments will be designed for an initial data collection effort. These experiments will be modeled around common construction activities. The model will be also validated in actual field construction activities. In particular, the proposed study includes the collection of individual and crew-level data on field construction activities. Skanska USA Buildings agreed to accommodate the field observations and provided permission to recruit workers on this project. A streamlined research plan is provided in Table 3, 4, and 5.

Table 3

Research plan - Phase I: planning and Model preparation

Task 1.1 - Identify work tasks. The authors will work closely with the industry partner to identify suitable labor-intensive work activities. Selected activities also need to be replicable in a lab environment. Several site visits, meetings and observations will occur as part of this preparatory task.

Task 1.2 - Identify task- and context-specific influencing factors. The authors have already reviewed more than 300 bibliographic sources and developed a general theoretical model. Therefore, this theoretical model will be perfected to generate a specific behavior-performance model in accordance with the task and contextual information collected in task 1.1.

Task 1.3 - Develop measuring methods and activities protocols. A successful completion of the lab and field observations will depend on a diligent plan for collecting and analyzing data. Thus, procedures for collecting, analyzing, and storing data will be developed. In particular, the authors will identify the most effective approaches to measure the model constructs (i.e., behavior, performance, and influencing factors) in accordance with the information from task 1.1. As part of this task, the authors will also meet with Skanska personnel to identify the most appropriate performance measures and resolve practical issues expected in the field.

Task 1.4 - Recruit and Enroll Subjects. As first part of this task, the authors will recruit subjects into two groups to participate in research activities: *Group (a)* will include experienced construction workers who will participate in both lab and field observations. *Group (b)* will include additional subjects who will only participate in the lab activities and may not have experience in construction.

Table 4

Research plan - Phase II: lab activities and model refinement

Task 2.1 - Pilot Lab Experiments. Before initiating the data collection, the authors will simulate activities to be performed by subjects to identify any needed change to the research measuring methods and activity protocols.

Task 2.2 - Perform Lab Observations. Lab simulated activities will involve two groups of subjects and replicate in the lab the same activities that will be observed in the field. However, lab observations will allow reducing and/or eliminating the effect of many influencing factors, including field-type pressures and interferences. The authors will hold three sets of lab observations:

(Set I) The authors will initially conduct simulated activities with *group (a)* subjects. Data collected in these sessions will be organized, so that the authors can compile them into individual and crew-level datasets. These datasets will provide a baseline measurement in a lab controlled-environment. Moreover, these lab activities will allow experienced construction workers to familiarize themselves with the data collection procedures in a controlled and safe environment.

(Set II) Later, the authors will ask *group (a)* subjects to hold short one-on-one training sessions where individual subjects from *group (a)* will train individual or groups of subjects from *group (b)* to perform the same task. This activity will reduce the amount of time needed for subjects in *group (b)* to learn how to perform each activity.

(Set III) Last, the authors will perform additional sessions with subjects in *group (b)*. These data will be used to refine the model. The collected data will include video camera recordings for performance and behavior analysis, and readings by Physiological Status Monitor (PSM) sensors and by an indoor environmental station for influencing factors analysis. In addition, subjects will be interviewed at the beginning of each session to assess the occurrence of any influencing factor, and at the end of each session to gain insight on potential issues that could arise while carrying out the field observation.

Task 2.3 - Data Analysis. The authors will analyze the datasets to test the expected relationships between performance and behavior, and physiological and environmental variables. At this time, the authors envision an analysis of variance of performance and behavior over time and across subjects. Further, the authors will perform regression analysis. In particular, the adequacy of the relationships will be verified by analyzing: (a) relationship overall significance with F-test; (b) individual predictor significance with t-test; and, (c) scatter plots of the residuals vs. each predictor and the predicted value (i.e., residual plots). Last, the coefficient of determination (R^2) and the Standard Error of Estimate (SEE) will be adopted to assess the statistical relevance of the relationships.

Table 5

Research plan - Phase III: field activities and model validation

Task 3.1 - Pilot Field Observations). Before initiating the field observations, the authors will work with Skanska personnel to observe field activities that will be monitored aiming at identifying issues with setting up the field instrumentation, and identifying any needed change to the protocols developed as part of Task 1.3.
Task 3.2 - Perform Field Observations. At this time, the authors envision collecting data on two crews of four workers each over a period of two weeks per crew at minimum. The authors will perform performance and behavior observations, and facilitate the field data collection effort by assisting workers. Data collected will include: (a) random clips of video recordings, (b) performance observations, (c) behavior observations, and (d) readings by PSM sensors and environmental station. In addition, subjects will be briefly interviewed at the end of the day to gain insight on issues occurred while participating in the field observation.
Task 3.3 - Data Analysis and Conclusions. Using these datasets, the authors will validate, and if necessary improve, the relationships tested in Task 2.3 using the data collected in the field observations.

Conclusions and Future Works

This paper describes the first step of a long-term objective focused on generating an effective and comprehensive behavior-performance model. In particular, this paper presents the experimental program developed to model the influence of worker's physiological status and jobsite physical environmental stressors on productivity, safety, and quality behavior and performance. First, the existing concepts, theories, and models from numerous disciplines reviewed to provide the theoretical grounding for the proposed program are discussed. Then, the main research objectives of the experimental program are presented. Finally, the designed research procedure involving the collection of data during lab simulated and actual field construction activities is described.

The intellectual merit of this research lies in the creation of an original workforce behavior-performance model that takes into consideration, for the first time, the influence of worker's physiological status and jobsite physical environmental stressors. However, numerous other influencing factors have to be considered to obtain a comprehensive behavior-performance model. Thus, the authors plan to complete the model in future contributions. Furthermore, the proposed research approach may be successfully applied outside the proposed scenario. For example, it could be applied to other labor-intensive industries, such as manufacturing.

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