AN ABSTRACT OF THE THESIS OF

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Over the decades, worker performance on construction projects has been a significant source of concern to be evaluated. Comprehensive studies have developed models for evaluating worker performance outside of the construction industry; however, minimal research has been conducted to evaluate worker performance in the construction industry. One of the reasons for a lack of similar research in construction is because the construction process makes construction more complicated compared to other industries. This research aims to further develop a new way of evaluating worker performance in the construction industry using the energy concept. Within the context of this research, “energy” is a property related to performing construction operations and can be defined as the feeling of stress, pressure, and being overwhelmed as a result of the factors, conditions, and resources that accompany the performance of the task. To develop the energy model, an initial conceptual model from previous research and literature review was used as a starting point.

The conceptual model contained three levels (constituents, components, and metrics) to measure the level of energy felt by a worker when performing construction operations. The Delphi method was utilized to identify, verify, and quantify the constituents and components, and confirm the energy model. The results from the literature review and Delphi survey revealed 14 constituents, 53 components, and one metric for each component to measure the level of energy. Constituents, components, and metrics were used to develop the energy model to evaluate worker performance on construction sites during a project and assess an ongoing project. The contributions of this research to knowledge are the validation and identification of the constituents, components, and metrics used for evaluating worker performance using the energy concept. The energy model contributes to evaluating worker performance in the construction industry based on the level of energy felt by the worker.

Evaluating Worker Performance Using the Energy Concept

by

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APPROVED:

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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Abdulaziz M. Alotaibi, Author

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# DEDICATION

In memory of my father Mutlaq M. Alotaibi (may Allah have mercy on him and forgive him). To my mother Zaheya D. Alotaibi, my wife Safiah Alotaibi, my daughter Lara Alotaibi, my brothers, and my sisters with love and eternal appreciation.

# 1. CHAPTER 1 – INTRODUCTION

## 1.1. BACKGROUND

In many ways, the growth of any nation can be measured by the improvement of its infrastructure, for instance, the country's buildings, roads, and bridges. Although the construction industry remains a significant factor for the development of any nation, construction project development depends heavily on quality and safety performance to measure the level of success (Roshana and Roshana 2002). Construction is becoming more complex to undertake from the start of work through planning, financing, designing, implementing, and final completion of a project (Wang 1994). To consider a construction project's success, projects should be delivered on time, on or under budget, according to the technical specifications, and to the client's satisfaction (Baker et al. 1983; Slevin and Pinto 1986; Morris and Hough 1987; Turner 1993). However, the preferred contractor is a contractor that delivers a construction project on time, without hindering worker performance and impacting safety and quality on the construction site.

Construction is one of the riskiest industries based on its dynamic, temporary, and decentralized nature (Heng Li et al. 2015). The construction industry is different from other industries because it has several unique features, including its structure, changing work locations (Building 1987), and complex work environments (Fang and Wu 2013), as well as, the characteristics of worker behaviors are not as standardized as workers in the manufacturing industry (Geller 2001a, b). Additionally, approximately 80% of accidents produce by human behavior on the construction site (Health and Safety Executive 2002).

The majority of fatalities are due to laborers falling from heights, and striking or being struck by moving objects (Hong Kong Special Administrative Region, Labour Department 2012). The construction industry has continued development to reach the high demands of the costly market; however, it has a wide range of challenges that exist in the field (Aksorn and Hadikusumo 2008).

## 1.2. RESEARCH PROBLEM STATEMENT

Mohamed (2002) states that when comparing the construction industry with other industries, construction shows a pitiful safety record. The reason is that construction process has the design and construction phases which are poorly strategic with significant lacks in the erecting, maintain, and demolishing of building and structures (Cooke and Williams 1998). Due to the complexity of the construction industry, the Construction Industry Institute (CII) has endorsed that there are factors such as safety, quality, and productivity that need to be measured to determine project performance (CII 2000). Resistance from the construction industry has resulted in the opposite impact of poor project performance (Nnaji and Gambatese 2016). The CII recommends that factors such as safety, quality, cost, schedule, changes, and productivity should be measured to determine project performance (CII 2000).

The construction process makes construction relatively complicated to study compared to other industries (William and James 1983). To evaluate worker performance on a construction site, a great deal of research has developed theories of worker performance outside of the construction industry (Campbell and Pritchard 1976) which can be applied to the construction industry.

Nnaji and Gambatese (2016) found the energy constituents and developed a new concept of using energy in the construction industry. Further research is required to verify/validate the constituents, determine their extent of the impact on the level of energy, and create a process for calculating the overall level of energy felt by a worker. This research is being conducted to identify and verify the essential energy constituents and components that the level of energy can be used to measure and the expected impact on safety and quality in the construction industry. The study involves obtaining input from a panel of experts in the construction industry using a multi-round survey process. The data will be used to develop an energy model for assessing worker performance relative to safety and quality on construction projects. However, the evaluation of safety and quality performance are not part of this current research. After the energy model is established, future research would involve a case study to examine the correlation between the energy model and key performance indicators such as safety and quality.

## 1.3. KEY TERMS

This section provides definitions of key terms that are important to this thesis. These terms are used throughout the thesis, and the differences between the terms might be subtle. Accordingly, it is significant for the readers to know and understand these subtle differences. The three levels of the model structure are constituents, components, and metrics, respectively. Each of the levels is briefly defined below:

### 1.3.1. CONSTITUENT

For this study, constituent refers to a condition of the work operation, work environment, and worker experience that impacts the level of energy felt by the worker.

### 1.3.2. COMPONENT

A component is defined as a performance criteria, action, or plan that can be used to assess a constituent. One or more components may be used to assess each constituent.

### 1.3.3. METRIC

A metric is defined as a scale that is used to measure each component.

## 1.4. THESIS STRUCTURE

To meet the objectives of this research, different tasks will be undertaken. These tasks are classed as chapters, as shown below:

**Chapter 1: Introduction**

The background of the study, the research problem statement, and key terms used throughout the thesis are presented in this chapter.

**Chapter 2: Literature Review and Summary of Energy Model**

This section begins with an introduction to the work performance operation of the construction industry. Also, general literature that describes evaluating safety and quality performance in the construction industry to improve work performance is presented. A new concept has been described from past study, which is how to asses quality and safety in the construction industry using the energy concept. The second part of this chapter describes the energy concept in the construction industry and its constituents and components. The last part of this chapter presents the gap in the literature and a new model to assess worker performance.

**Chapter 3: Methodology**

This chapter presents the research questions that should be asked and answered. In addition, the research goal, objectives, and methods for data collection and analysis are also discussed in this chapter.

**Chapter 4: Results**

This chapter of the thesis is provided initial results of the Delphi process. The Demographic Information of panelists, constituents, and an initial list of components are presented in this chapter.

**Chapter 5: Analysis and Discussion of Results**

This chapter of the research displays analysis and discussions of results from the Delphi process to answer research questions.

**Chapter 6: Developing Energy Model**

This chapter described and provided detailed explanations of the energy model and answered other research questions.

**Chapter 7: Conclusions and Recommendations**

This chapter presents the research conclusions, limitations, and recommendations for future studies.

# 2. CHAPTER 2 – LITERATURE REVIEW AND ENERGY MODEL

## 2.1. INTRODUCTION

To help measure the level of project performance, it is important to determine the level of energy for group tasks on site. According to Dai et al. (2009), methods of predicting project performance need to be developed. To do as recommended in this statement, the impacts of project factors, resources, and site conditions on project performance criteria, such as worker safety, should also be developed (Nnaji and Gambatese 2016). Factors such as work complexity and distractions can have a significant impact on more than construction just key performance indicators (KPI) (Hinze 2006). Therefore, if this research can determine factors that affect project performance, it might also contribute to improving project performance.

In the last 30 years, many researchers have strived to produce or distribute knowledge about how to improve safety and quality performance (Wanberg et al. 2013). Researchers have investigated safety and quality performance. Examples of research topics include: safety at a number of levels such as personal distraction that lead to fatalities (Hinze 1997); project level factors linked to the direct physical environment such as work visibility and heavy equipment (Hinze and Teizer 2011); the interaction between construction safety and design (Gambatese et al. 2005); and a recent study is safety knowledge management (Hallowell 2012). However, accidents and injuries still continue to occur on construction projects.

In this chapter, emphasis is placed on evaluating work operations in construction through safety and quality performance. Energy concepts in the construction industry and energy constituents are also emphasized along with the measurement of energy levels on construction sites to evaluate work operations for safety and quality performance. In addition, by formulating kinetic and potential energy to measure the energy on construction sites, the energy in construction has some constituents such as crowding and complexity. Lastly, the impact of energy to improve quality and safety will be investigated through a literature review to find a gap in knowledge related to the topic.

## 2.2. EVALUATING WORK OPERATION IN CONSTRUCTION

Due to its dynamic and complex nature, construction is one of many industries that is difficult to evaluate with certainty. A construction project involves different phases and stages, various processes and operations, and a significant amount of coordination between numerous parties (Chan et al. 2004). A successful construction project can be difficult to define (Lam et al. 2008; Toor and Ogunlana 2010); however, it can be delivered on time, within budget, and meet client satisfaction and specification. (Baker et al. 1997; Cooke-Davies 2002; Morris and Hough 1987; Pinto and Slevin 1987). The measurement of project success has led to innovative tools and resources. Some methodologies and concepts have been developed to consider the long term aim of improving overall project performance and operations.

Construction operation has been evaluated using some strategies and methods such as total quality management (TQM), total quality management (TQM), plan do check act (PDCA), cost variance, earned value, and milestone variance (Cheung et al. 2004; Howes 2000; Kim and Reinschmidt 2011; KWAK and IBBS 31 2000). These methods lack the predicative skill to identify problem areas, thereby making the methods mainly reactive (Choi et al.

2006). Stakeholders have expressed anxieties about the ability of these methods to provide a full evaluation of project performance (Kaplan & Norton, 2005).

### 2.2.1. EVALUATING SAFETY PERFORMANCE

Despite a larger number of academic researchers having tried to improve safety performance, near misses and severe accidents still happen (Hallowell 2011 and Wu et al. 2017). A safety performance evaluation is a part of a safety management system because it provides information to develop and implement the system's quality (Sgourou et al. 2010). In previous research, the usual approach for evaluating safety is through measurement of the number of accidents and severity rates that are referred to as retrospective or lagging indicators (Sgourou et al. 2010). Choudhry (2014) described the traditional index system focused on the numbers of accidents. However, less attention is paid to the internal factors such as safety attitude, safety climate, safety behavior, and safety culture (Xianguo Wu et al. 2015). Therefore, there is still a long way to go to achieve the goal of reducing accidents in the construction industry.

The previous research on safety performance evaluation methods has suggested the use of metrics, such as experience modification ratings (EMR), for evaluating safety on construction projects. High EMR values cost companies more than expected because of their impact on worker's compensation insurance premiums (Thomas Ng et al. 2004). Since the EMR calculation is complex and involves a diverse set of calculations (Everett and Thompson 1995), solely using EMR is not an appropriate metric to evaluate safety performance (Hinze et al., 1995). Thus, Levitt (1987) stated that this metric could not be practically used for current projects to evaluate safety performance.

Another metric that could be used is accident rate (AR). Tam and Fung (1998) conducted a study of using AR to measure performance, however the number of accidents has long been considered as an unsound basis for comparison. The reason for this perspective is that contractors may not be motivated to report the number of accidents accurately (Thomas Ng et al. 2004). Moreover, the researchers considered that the incidence rate (IR) could be added as one of the safety performance evaluation criteria based on the number of lost time cases, number of days lost for all loss of time cases, and the number of fatalities, injuries, and illnesses with or without lost workdays. Conversely, the IR may not be an accurate measure for evaluation performance because it depends on a computation process (Jaselskis EJ et al. 1996).

The purpose of evaluating safety is to prevent worker injuries and fatalities. As mentioned above, construction sites are not as safe as other industry work sites and, consequently, construction has gained an undesirable reputation in relation to the health, safety, and welfare of its worker (Ikpe et al. 2012). Additionally, in 2015, 985 construction workers died from work-related injuries, which amounts to 20% of the 4,836 fatal injuries that occurred in all workplaces in the United States The number that occurred in construction is more than other industry, as shown in Figure 2.2. (CPWR Construction Chart Book, 6th Edition, February 2018).

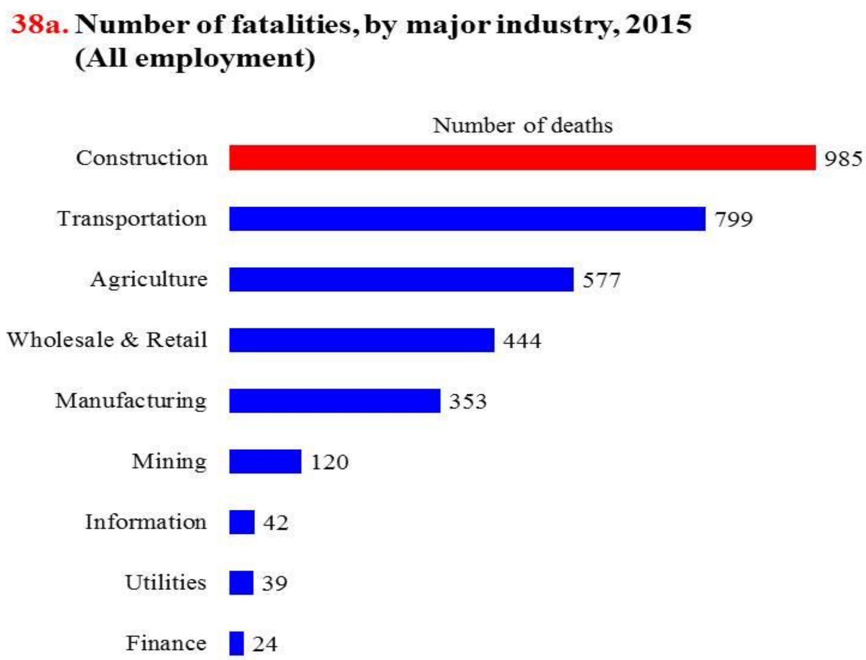


Figure 2.1: Fatalities by Industry (CPWR Construction Chart Book, 6th Edition, 2018)

In general, evaluating safety performance in construction is connected with factors such as psychological, technical, procedural, organizational and work environment issues (Sawacha et al. 1999). Despite the many studies that have shown multiple ways of evaluating safety performance, the construction industry has experienced the highest level in fatal injuries, as seen in the fatality data released in 2018 by U.S Bureau of Labor Statistics as shown in Figure 2.4. Rajendran (2013) reported that more research and studies are needed to improve safety performance in the construction industry.

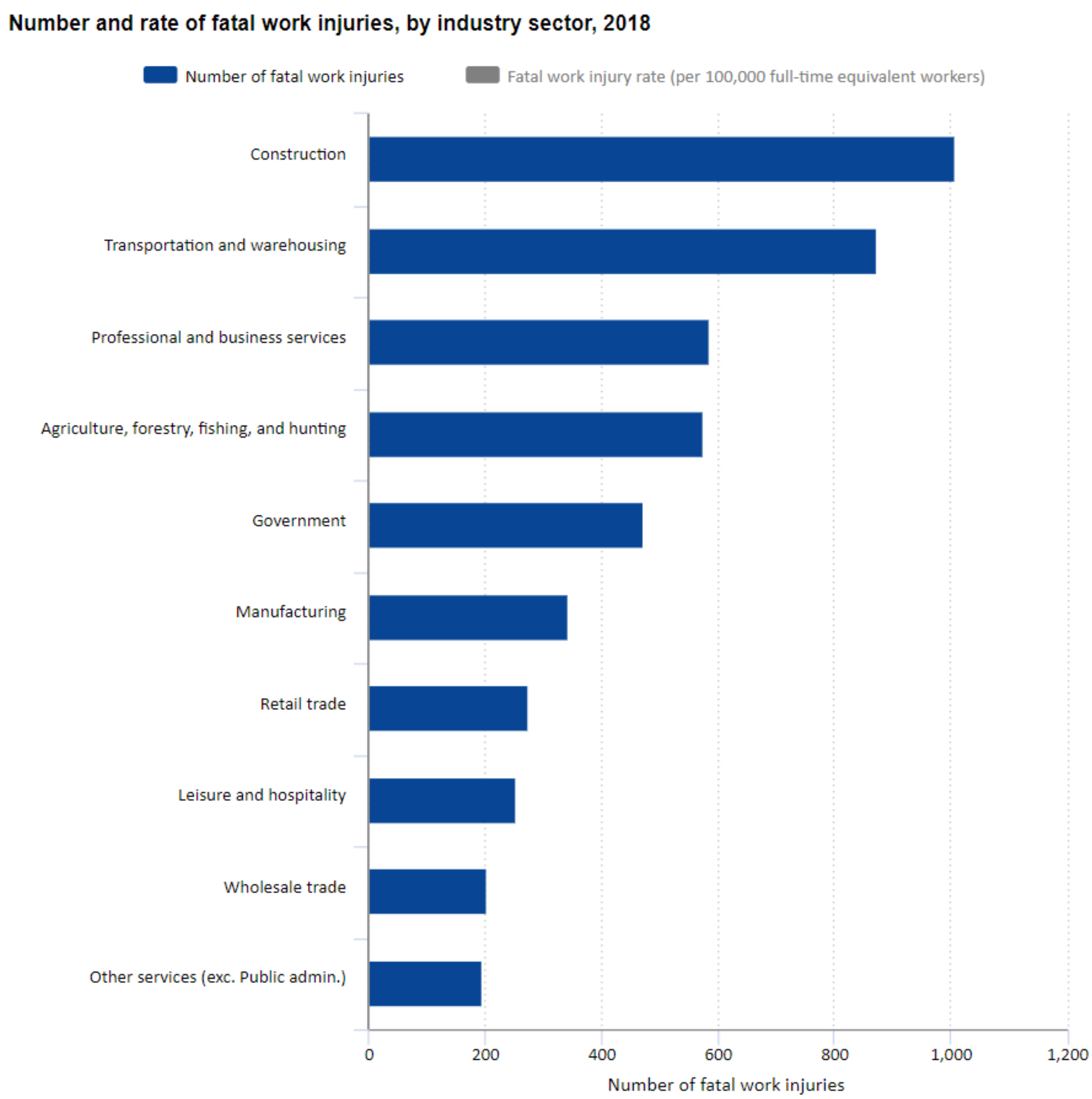


Figure 2.2: Number and rate of fatal work injuries, by industry sector (U.S Bureau of Labor Statistics)

The Occupational Safety and Health Administration (OSHA 2014) reported that evaluating safety problems should be carried out prior to project commencement and appropriate safety measures should be established in place to control issues that may arise. The main causes of injuries and accidents on construction sites are published by OSHA (2014) and are responsible for 58.7% of all accidents in construction. The main causes are:

i. Fall from height
ii. Struck by an object
iii. Electrocution
iv. Caught in/between

Similarly, based on studies performed by Heinrich in 1931, Johnson (2011) and Manuele (2011) describe how the accident causes can be divided into three major categories: (1) unsafe acts of persons (88%), (2) unsafe mechanical or physical conditions (10%), and (3) unpreventable (2%), as shown in Figure 2.5.

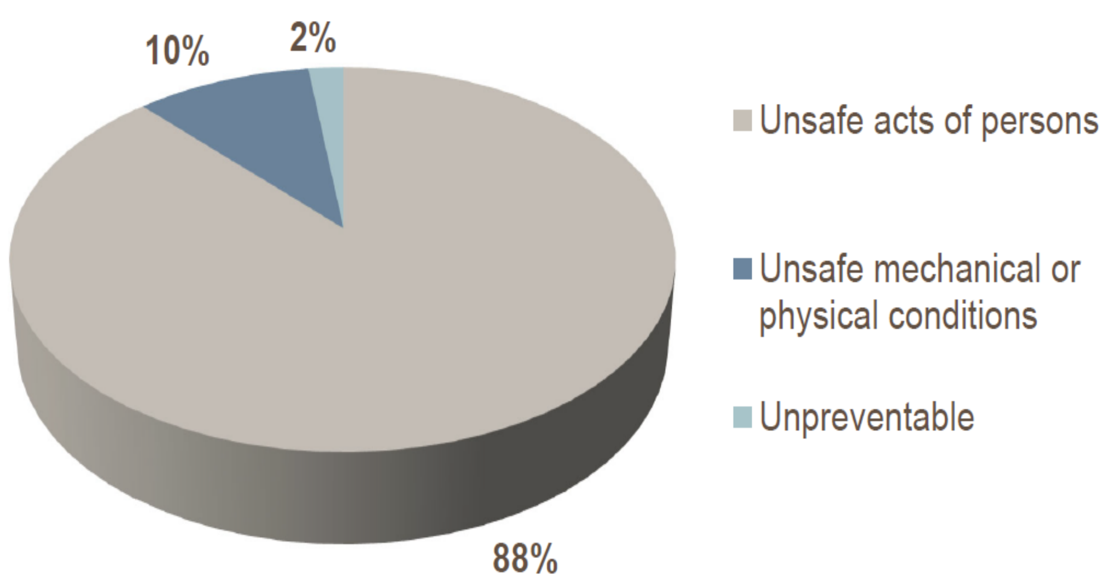


Figure 2.3: Causes of Accidents (Johnson, A. 2011; Manuele, F.A. 2011)

To this effect, several safety tools and models have been developed to reduce the number of accidents. The Construction Users Roundtable (CURT), OSHA, and the Construction Industry Institute (CII) report qualitative safety performance criteria within the construction industry such as standardized benchmarking systems. In addition, a Health and Safety Continuous Improvement Matrix was developed and given to the Australian construction industry by the Industry Development Agency (CIDA 1995) to create the measurements to compare OHS performance across the industry. To counter the identified safety concerns related to the absence of a recognized mechanism, Hallowell and Gambatese (2009) presented and confirmed a risk-based safety and health model to help contractors select elements to include in safety programs given specific employee activities and risk exposures.

New technologies have led to a new dynamic in accident prevention through design. Technologies such as BIM can be used to eliminate hazards in the design phase of a project (Hayne et al. 2014; Kasirossafar and Shahbodaghlou 2012a). Visualization tools could also be used to improve safety through efficient planning and coordination of construction operations (Kasirossafar and Shahbodaghlou 2012b).

### 2.2.2. EVALUATING QUALITY PERFORMANCE

The definition of quality in the construction industry has been changed over the decades. Quality has been defined as “fitness for purpose” (Juran and Gryna 1993), whereas Latham (1994) defined quality in the construction industry as the value of money spent on a project. The main benefactor from project quality is the client who is closely connected to the quality of the project (Latham 1996). Similarly, quality has been defined as “*the means of* *meeting requirements of all costumers"* (CII 1994). Construction quality is defined as conformance to established requirements through some documents such as plans, specifications, and contracts (Ashford 1989). The Construction Users Roundtable (CURT 2005) defined construction quality as an achievement to required performance specifications.

When construction quality is reactive, issues are established and resolved after work is completed, thus, increasing rabidly the amount of rework and cost expected. Love (2002) reported several types of rework, including quality deviations, nonconformance, defects and quality failures (Burati et al. 1992; Abdul-Rahman 1995; Josephson and Hammarlund 1999; Barber et al. 2000). Consequently, the percent cost of rework and rate of construction defects are the primary indicators of construction quality (Wanberg et al. 2013). The cost of projects that is spent on rework ranges from 5% to 20% according to Burati et al. (1992), CII (2005), Hwang et al. (2009), and Joseph and Hammarlund (1999). Joseph and Hammarlund (1999) found the cost of nonconformance was between 2.3% and 9.4% of the total project costs. Thus, given the total value of construction put in place, the total cost of rework across the industry would amount to between \$15 billion and \$150 billion (US. Department of Commerce 2014; United States Census Bureau 2014; Worldbank 2015).

Not only is cost and time related to quality an issue, the consistent occurrence of performance impacts such as construction errors that lead to rework is alarming (Boukamp and Akinci 2004). Some factors have been identified as the reason for poor quality performance on a project such as the complex nature of the industry, lack of planning, project type, safety culture, quality assurance, and lack of standardization and specifications (Hoonakker et al. 2011; Lopez and Love 2012; Love and Smith 2003). Deviation from the design and specifications is one major cause of poor quality and costs approximately 12.4% of total project cost (Arditi and Gunaydin 1998). Burati et al. (1992) investigated the causes of deviation on nine projects to identify the causes and number of quality problems, and found the 19 deviation categories for classifying project data shown in Table 2.1.

Table 2.1: Deviation Categories Used for Classifying Project Data (Burati et al. 1992)

| Deviation | Description |
|---|---|
| Construction change | Change in the method of construction |
| Construction error | Error made during construction |
| Construction omission | Omission made during construction |
| Design change/improvement | Design revision, modifications, and improvements |
| Design change/construction | Design change initiated by construction |
| Construction change | Change in the method of construction |
| Construction error | Error made during construction |
| Construction omission | Omission made during construction |
| Design change/improvement | Design revision, modifications, and improvements |
| Design change/construction | Design change initiated by construction |
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| Construction change | Change in the method of construction |
| Construction error | Error made during construction |
| Construction omission | Omission made during construction |
| Design change/improvement | Design revision, modifications, and improvements |

Table 2.1 highlights that quality issues can be present in all phases of a project. The results from the Burati et al. (1992) study reveal that design deviation as a percentage of the total number of deviations on a project ranged from 67-90%, while construction deviations were between 5-29% of the total number of deviations.

In an attempt to improve quality on a construction project, the Total Quality Management (TQM) concept was implemented in the 1980s. Also, the Plan Do Check Act (PDCA) process, shown in Figure 2.6, was established to confirm that the quality process is enhanced continually. Deffenbaugh (1993) stated that TQM could be used to correct some issues on a project such as lack of teamwork, poor communication, and inadequate planning and scheduling. TQM decreases the cost of projects, improves a contractor's standing, and increases customer fulfillment (Graves 1993; Lester et al. 1992; Rounds and Chi 1985).

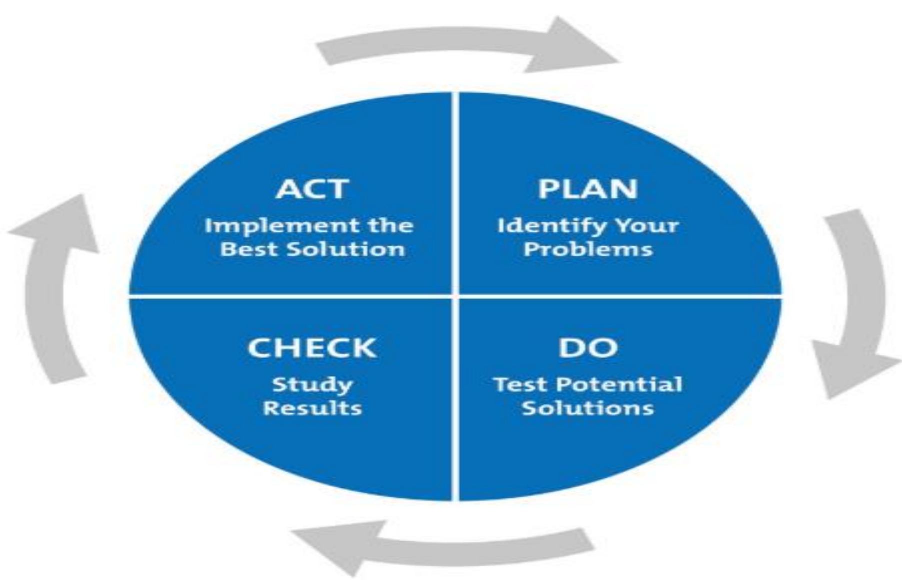



Figure 2.4: The Plan-Do-Check-Act Cycle (The W. Edwards Deming Institute)

Several tools and models for measuring quality on a construction project have been developed over the years to improve the quality of construction projects, such as the Performance Assessment Scoring System (PASS) (Coffey 2008). On the other hand, increasing quality comes as a cost for projects. Cost of quality (COQ) was first discussed by Juran in 1951. Companies lose some amount of money if the result is in nonconformance to the specifications and requirements of clients. Therefore, Cost of quality can range from 15% to 40 % of the total project cost (Waje 2002).

To clarify the cost of quality on projects, Kazaz (2004) divided cost associated with maintaining quality into two components: (1) proactive costs (prevention and appraisal cost), and (2) reactive costs (cost due to internal and external failures)". One of the ways to decrease the cost associated with defects and rework on a project is to increase the cost associated with prevention and appraisal (Brown and Kane 1984), as shown in Figure 2.5.

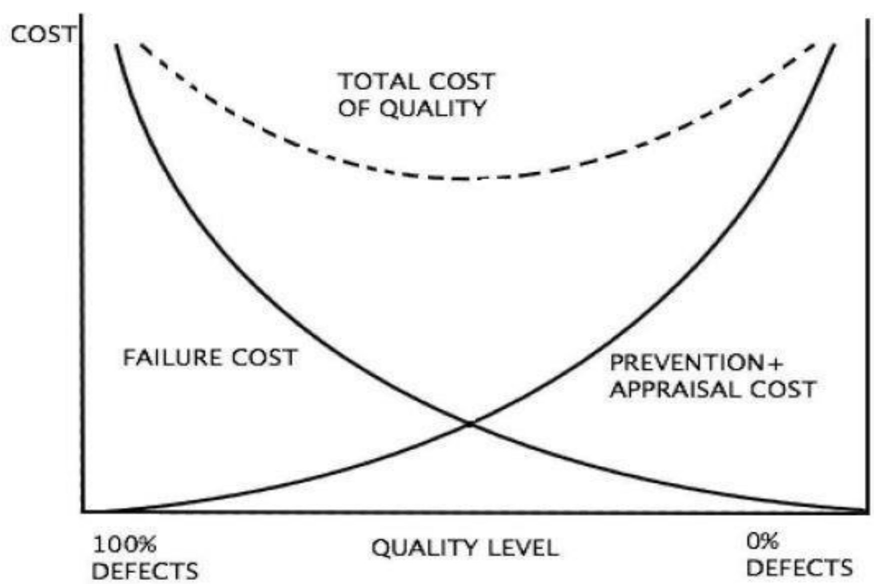



Figure 2.5: Cost of Quality (Brown and Kane 1984)

Despite the large number of studies or models that have been undertaken to evaluate work performance or work operations for safety and quality in construction, none of the researchers have evaluated work operations for safety and quality using the energy concept (kinetic energy and potential energy).

## 2.3. ENERGY CONCEPT IN CONSTRUCTION

### 2.3.1. ENERGY DEFINITION

According to previous research, energy is the ability to do work. That is, a worker should have energy to complete work (Nave 2005). Additionally, energy is transferred between portions of a system in the production of physical change within the system regarded as the ability to perform work (Merriam- Webster.com). In other words, energy is the ability to do work (U.S. Energy Information Administration). Finally, energy can be defined as the capacity for dynamic activity (Dictionary.com). Aggregating all of these definitions from different sources and authors, energy can be defined as the capacity or ability to accomplish physical or dynamic work.

In the construction industry, field workers perform many different operations related to the planning, fabrication, construction, maintenance, and demolition of structures, roads, bridges, buildings, and more. Nnaji (2015) has defined the ability to carry out work as the factors, conditions, resources, and activities needed to execute work. For the context of this research study, "energy" can be defined as the combination of the stress, pressure, and feeling of being overwhelmed while performing the task. Further explanation of this feeling of energy is provided in Section 2.4. The energy referred to in this study can be also described as the energy on a worker to perform the task. As an example, for a work task that is complex or unique, a worker might feel more energy while performing the task. Similarly, if the task has a short time to be completed, a worker might feel more energy before the task has yet started.

Physical energy is needed to perform the work. This study does not include the physical energy expended to perform a task (e.g., the energy needed to lift a heavy object or for a worker to walk from one place to another). It is proposed that workers also experience a feeling of "energy" as they perform their work. That is, energy is a property related to performing construction operations and can be defined as the feeling associated with the factors, conditions, and resources that accompany the performance of the work. Constituents of energy (e.g., complexity of work, uniqueness of the work, etc.), which will be defined in more detail below, can influence this property (Nnaji 2015). The constituents may add to a low or high level of energy felt by workers as they perform their work.

Energy exists in several different forms. All forms of energy are either kinetic energy or potential energy. Every type of energy associated with motion is called kinetic energy (KE), and the energy associated with position is called potential energy (PE) (Elert 1998) . With respect to work sites and operations, the form of energy that is utilized in construction work is the physical form of energy, which can be divided into both KE (i.e., working energy) and PE (i.e., stored energy) (Watson 2014; US Energy Information Administration 2014).

The level of "energy" felt by a worker in the performance of their work has been the focus of previous research which has formulated equations for both KE and PE to be applied to the construction site. These energy terms with respect to what is felt by workers in the performance of their work can be defined as described below. Also, construction workers are exposed to the physical aspects of performing a task such as repetitive motion (lifting/lowering). The physical energy is included in the energy concept as Nnaji (2015) summarized that the energy felt by workers while conducting work as shown in Equations 2.3. From a physical object perspective, the physical demand related to work assignment differs from task-to-task.

### 2.3.2. KINETIC ENERGY (WORKING ENERGY) (KE)

Kinetic energy has different definitions; Table 2.2 below provides some sources that have defined this type of energy.

Table 2.2: Kinetic Energy Definitions

| No. | Definition | Source |
|---|---|---|
| 1 | *"Kinetic energy, the energy is an object has because of its motion, as well as, it depends on the mass and velocity reached."* | KhanAcademy.org and Live Since.com, 2014 |
| 2 | *"It is the energy of mass (an object) in motion (moving)."* | SolarSchools.net |
| 3 | *"The energy of an object is the energy it possesses because of its motion."* | Nave, 2014 |

Although the previous definitions of kinetic energy are similar, KE can be summarized that the energy of a body with respect to its motion (movement) (Nnaji 2015). In addition to the definition of this type of energy, kinetic energy (KE) has two components, namely mass and velocity, as shown in Equation 2.1:

$$KE = \frac{1}{2}mv^2 \qquad \text{(Eqn. 2.1)}$$

Where: $m$ = mass of object

$v =$ velocity

The unit of measure commonly used to quantify kinetic energy joule.

The previous information relates to kinetic energy associated with the movement of an object. Translating this concept to construction work, kinetic energy is identified as the work expended in performing a task (Nnaji 2015). To clarify, various tasks are obligatory to attain the goal of a construction project. At this point, it is important to discuss the meaning of “task” in construction and factors that impact performing tasks, as described by a number of researchers. Nnaji believes that every task has some different factors that might improve or inhibit the ability of a worker to effectively undertake it. To put it another way, Antunes and Gonzales (2015) and Frimpong et al. (2003) have noted that several factors have a significant impact on project tasks such as complexity, repetitiveness, uniqueness, availability of resources and predictability.

Construction workers are, by virtue of their tasks, exposed to elevated physical risk factors such as repetitive motion (lifting/lowering) (Antwan-Afari et al., 2017). As a final point, these findings have important consequences to the formulated energy equations by Nnaji and Gambatese (2016). Equation 2.1 shows the relationship between factors:

$$NT = \frac{\text{(Complexity)(Uniqueness)}}{\text{(Predictability)(Repetitiveness)(Availability of needed resources)}} \qquad \text{(Eqn. 2.1)}$$

Where: NT: nature of the task

Nature of the task (NT) is a measurable total of the energy components that affect a work task (Nnaji and Gambatese, 2016). Indeed, NT could be work that is carried out. The factors that comprise NT are namely: complexity, repetitiveness, uniqueness, availability of resources, and predictability as shown in Equation 2.1, which will be clarified in the Section 2.3.4 below. In construction, KE can be viewed as the work done in completing a task. In addition to nature of task, execution of task needs to be clarified as it relates to kinetic energy.

Execution of the task (ET) is a measurable total that applies to the energy associated with components linked dynamically to execution the work task (Nnaji and Gambatese, 2016). Besides the previous energy variables, there is also another factor that may be observed when executing tasks. Nnaji (2015) states that the factors that influence execution of the task are pace, crowding, interruptions, distractions, and switching between tasks. Nnaji developed an equation to quantify ET, which is:

$ET = (\text{pace})[(\text{crowding})(\text{interruptions})(\text{distractions})(\text{switching between tasks})]$ (Eqn. 2.2)

Where: Pace of work can be represented as time taken to get a specified amount of work done.

For application to construction operations of the physical form, Nnaji (2015) summarized that the energy felt while preforming work to be as shown in Equation 2.3.

$KE = \sum_{i=1}^{n} (Nature\ of\ task)(Execution\ of\ the\ task)$ (Eqn. 2.3)

### 2.3.3. POTENTIAL ENERGY (STORED ENERGY) (PE)

Potential energy is energy associated with the static position of an object. It has been previously defined as shown in Table 2.3.

Table 2.3: Potential Energy Definitions

| No. | Definition | Source |
|---|---|---|
| 1 | *"Potential energy results form a position or arrangement."* | Nave, 2014 |
| 2 | *"Potential energy is a stored energy that relies on the position of the body or arrangement of the object."* | SolarSchools.net |
| 3 | *"The energy of a body or a system with respect to the position or arrangement."* | Dictionary.com |
| 4 | *"Potential energy is the energy an object has because of its position relative to some other object."* | Chem.wisc.edu |
| 5 | *"Potential energy exists based on the relative position of the object within a physical system."* | Sciencedaily.com |

From a physical object perspective, potential energy can be derived from three components, which are mass, gravity, and height. Potential energy is the type of energy that remains present even when there is a lack of motion. To conclude, as shown in Equation 2.3, the equation for potential energy depends on the force or weight acting on an object and its distance above the earth:

$$P.E. = mgh \qquad \text{(Eqn. 2.3)}$$

Where: m is the mass, g is the acceleration due to gravity, and h is the height.

In particular, the difference between kinetic energy and potential energy is that potential energy is stored energy, whereas kinetic energy is the energy of motion. For example, assume there is a car on a hill. When the car is parked at the top of the hill, it has potential energy. Once the car starts moving down the hill, the potential energy directly transfers to kinetic energy.

From a construction perspective, potential energy has been defined as the effect of a task (work) that has been given to a worker to perform; however; the task has not yet been executed (Nnaji, 2015). It should also be noted that a high level of potential energy might raise the pressure on a worker and, consequently, it could lead to potentially low worker performance.

Nnaji (2015) identified two components that determine the potential energy felt by construction personal. These energy components are the number of tasks and the nature of the tasks listed to be carried out by a worker and the burden associated with completing the undone assigned tasks. The first component is the same characteristic as for NT with respect to KE, while the second component is identified as the demand to complete all tasks (DCT). DCT represents gravity and height in the equation for PE. Nnaji reported that two factors are considered to have extensive influence on the level of stress felt by workers. These two factors are (1) time to complete all tasks, and (2) value of task.

As a result, from the two parts described above, Nnaji (2015) found that the time between a continuing activity and the time remaining before the deadline for completing the activity could affect the energy felt by a construction worker. The construction industry undertakes many different activities such as formwork erection, concrete pouring, installation of steel frames, etc. Consequently, if these activities are being conducted close to the deadline for completing the activity, the workers will feel a sense of anxiety. The occurrence of this “anxiety” is referred to as the demand factor (DF). Equation 2.4 shows how DF is calculated.

$$DF = 1 + \frac{\text{Duration of task}}{\text{Time remaining before the deadline}} \qquad \text{(Eqn. 2.4)}$$

Demand factor signifies to the pressure created between the duration of the task and the time remaining to finish the task (Nnaji and Gambatese, 2016). The researchers observe that a higher value of DF will lead to higher potential energy. Subsequently, the degree of DF could play a major role in increasing or reducing the amount of potential energy. Additionally, the demand the complete all tasks (DCT) is divided into two parts: (1) value of all tasks, and (2) time to complete all tasks. DCT is also multiplied by DF to incorporate the impacts of task duration. DCT can be derived as shown in Equation 2.5:

$$\text{DCT} = \left[\frac{\text{Value of task}}{\text{Time to complete all tasks}}\right](\text{DF}) \qquad \text{(Eqn. 2.5)}$$

Hence, for the energy felt by a worker performing a construction operation, PE can be derived as shown in Equation 2.6

$$PE = \left[\sum_{i=1}^{n}(Nature\ of\ task)\right](Demand\ to\ complete\ all\ tasks) \qquad \text{(Eqn. 2.6)}$$

Nnaji (2015) reported that the purpose of “pace of work” in kinetic energy is to equate the amount of work done (in dollar value) over a certain amount of time. Likewise, potential energy (PE) is defined in construction as the value of the tasks over the time to complete all tasks. As a result, both forms of energy have work done over a given time. Thus, the unit that will be proposed for measuring energy in construction is $/time.

### 2.3.4. ENERGY CONSTITUENTS

Both kinetic energy and potential energy are envisioned to be composed of specific elements that can be used to quantify KE and PE. Nnaji (2015) proposed that the constituents of energy consist of complexity of the task, uniqueness of the task, predictability of the task, repetitiveness of the task, availability of needed resources, duration of the task, time remaining to complete the task, crowding, coordination, value of the task, interruptions, distractions, pace of the task, and switching between tasks. Descriptions of each of the energy constituents are provided below.

**i. Complexity of the task**

Most systems are complex, even in construction. Several authors have defined complexity in construction from different perspectives. Williams (1999) typifies complexity as structural uncertainty and uncertainty in goals or methods, whereas, Bertelsen (2004) proposed that complexity reflects a series of characteristics which are not found in an ordered system. Beterslen (2004) defined complexity in construction from three perspectives:

i. The process of a project is more complicated, parallel, dynamic, and different than traditional project management. The inaccuracy of the traditional project management perspective is the ordered view of the surrounding world. To illustrate, supplies and resources are assumed to be ready according to the project's schedule, so any changes will not occur. As a result, traditional project management processes are not the way the system operates.

ii. Most construction projects are divided into parts such as subcontracted to individual enterprises. The construction industry is extremely disjointed; its organizations cooperate in ever-changing patterns, and project participation is commonly decided by the lowest bid for the project.

iii. The construction site is a workplace for humans and a place for teamwork and social interaction because of transient social system. This aspect is based on the workers' loyalty to their firm and the job at hand.

On the other hand, the results of the research conducted by Xia and Lee (2004) indicate that complexity is associated with delays, cost overruns, restrictions of system functionalities, and reduction of user satisfaction. In general, complexity is the number of elements and relations, and the strength of influence of a defined system with regard to making a decision (Christian and Kalle 2012). The researchers also found that task complexity can be divided into two parts, time pressure and space limitations, both of which increase complexity. To put it another way, construction is an industry that has a dynamic nature and unpredictable changes that might lead to complexity (Marzouk and Ali 2013). For instance, during operations, construction sites have different complexity due to the need for many types of crews and equipment in the same work area. All crews and equipment need space to move in order to perform the work safely and with high quality. To conclude, space might have an effect on worker performance.

Nanji (2015) described complexity of the work as follows: "The mental and physical demand related to a work assignment differs from task-to-task. In some cases, a task is multifaceted, intricate, and complicated, and may require significant thought and special skills to perform. Tasks that are highly complex can exist on any type and size of project." Thus, there are some components that impact complexity of the work such as project size, project budget, etc. Nanij showed that even though complexity of the work presents a low impact on safety, its impact on quality is highly significant. The results, based on the survey responses, revealed that some project engineers feel that complexity has some degree of impact on safety at certain task levels while other project engineers believe complexity has a slight impact on the safety of their work.

**ii. Uniqueness of the work**

The construction industry has been plagued with a lack of information in previous decades. Francis and Sidwell (1996) pointed out that it is important to consider the uniqueness of the construction industry. The first time any person performs a unique task, they may work gradually (Dozzi and AbouRizk 1993) or get injured due to a lack of experience and knowledge about how to do it.

Nanji (2015) defined uniqueness of the work as tasks required to produce a project that differ from regularly-performed work and are unique to the project. Construction employees who lack experience may not be familiar with performing such unique tasks. Nanij (2015) found that although uniqueness of task has a small impact on worker performance indicators related to safety and quality, it could impact other project indicators such as productivity. Hence, uniqueness of the work is retained as one of the energy constituents.

**iii. Predictability of the task**

Predictability of the task has been defined as a key aspect that influences task performance in construction industry (Nanji 2015). As a result of Nanji’s study, if the task is more predictable, it could improve the safety and quality performance of construction personnel.

Alarcon (1997) also recognized predictability of the task as one of the significant factors that improves work flow.

Antunes and Gonzales (2015) and Frimpong et al. (2003) found that construction is uncertain, and project managers develop methodologies to help update processes in construction operations. Nanji (2015) included predictability of the task since construction often incorporates uncertainty in the work performed. While processes have been developed to simplify and streamline activities, some tasks associated with an activity may be unpredictable due to a lack of information about the task, a lack of requisite skills by the workers, or uncertainty about the jobsite conditions, and other work operation conditions (e.g., unpredictability of the work tasks due to unknown information).

**iv. Repetitiveness of the task**

Repetitiveness of the task delivers the chance for efficient use of instructions learned, and unavoidably proportionating improvement in processes and products (Antunes and Gonzales 2015). Cho et al. (2010) and Spencer (1995) found that the highest level of repetitiveness might lead to constant productivity due to product likeness; however, construction produces multiple products (Spencer 1995).

Furthermore, repetitiveness has been defined as a "*closed loop system where deviations might be used as input to correct and control current and future system output"* (Antunes and Gonzales 2015; Hopp et al. 1996). Nanji (2015) defined repetitiveness of the task as when a task is required to be executed often by a worker, the worker will find the task to be repetitive and may feel differently about the task compared with other, less repetitive tasks performed. Differences in task performance may be a result of familiarity developed over time (e.g., learning curve, task is extremely repetitive). As a result of Nanji's study, workers will be less stressed after performing more repetitive tasks many times.

**v. Availability of needed resources**

Availability of resources to complete the task can have a significant impact on work performance. To confirm the nature and extent of the impact, Nanji (2015) reported that resources (e.g., materials, equipment, labor, etc.) are a significant part of all construction projects, and resource availability is a critical factor for the work to be accomplished. Tukel and Rom (1998) also identified availability of resources as a significant key performance constraint in projects even in the construction industry. In addition, a lack of resources has been identified by some researchers as an influential factor. The lack of resources is a major warning sign of lowered construction productivity (Olomolaiye et al., 1996; Rojas and Aramvareekul 2003; Motwani et al. 1995).

**vi. Duration of the task:**

The construction industry is one of the industries that deals with variations in plans and specifications until a product is completed (Peurifoy and Ledbetter 1985). Each task on a project is typically assigned a duration (Russell et al. 2014). This duration helps management verify the progress of a project. In certain cases, the prescribed duration of a task could impact the worker's performance (e.g., if the required task duration is reduced significantly to accommodate a change in project schedule). Lock (1996) reported that it is important to know the estimated activity duration to improve work efficiency and reduce mistakes and misunderstandings.

### vii. Time remaining to complete the task:

Commonly in construction, each activity or project duration should be completed in a certain amount of time, or by or before a specified date (Hanna et al. 2005). A key factor that affects the performance of project is time constraints. Time constraints could be related to financial issues, resource availability, seasonal concerns, and other factors. To eliminate time constraints on a project, workers are required to perform one task before moving forward to the next task to keep the project ahead of schedule; hence, workers may be under stress to complete all tasks if the time remaining is less than the time needed. Stress can be defined as a feature of the external environment that acts on an individual and a response of an individual toward the environmental demands, pressures, and challenges, or the interaction of both (Ganster and Perrewé 2011; Kahn & Byosiere 1992). Sutherland and Davidson (1993) identified time pressures as a significant factor that impacts the level of stress amongst worker.

Nnaji (2015) indicate that stress could be related to the number of tasks that workers are required to finish within a certain period of time. According to the Adjustment-Stress Theory (Hinze, 2006), workers will be safer in a positive environment that reduces the level of stress. Similarly, unusual, negative, and distracting stress placed on workers increases their susceptibility to an accident or other low-quality behavior. In other words, stress distracts workers’ attention and might lead to increased probability of an injury.

In most cases, workers have several tasks lined up to work on for a project. Each task should be completed within a specific duration. However, as workers approach the stipulated completion time, they could be under additional pressure due to the amount of work still to be completed within the time remaining to complete the task.

**viii. Crowding:**

Crowding can be defined as the situation when more crews are placed in a given space than can function effectively. Crowding may occur when the contractor attempts to complete more work activities in shorter period of time (Dozzi and AbouRizk 1993). Consequently, as the number of workers is increased in the same place, safety, quality, and productivity will be affected. Langer and Saegert (1977) found that crowding could be stressful and impacted task performance. Similarly, Dozzi and AbouRizk (1993) reported that the work space per worker has an effect on work efficiency. Figure 2.6 shows the percentage of the loss in efficiency as the percentage of crowding increases.

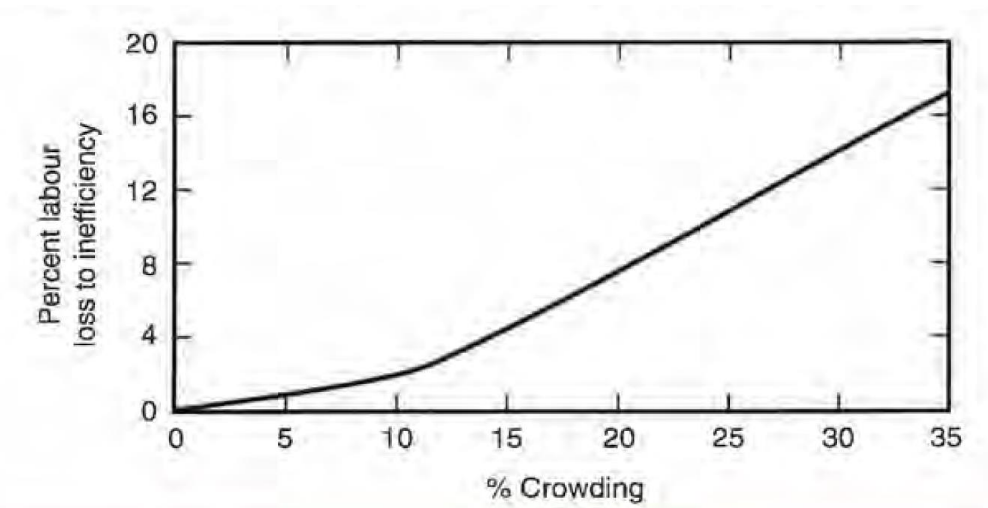



Figure 2.6: Effect of congestion of trades (crowding) (Adapted)

As indicated by Nnaji (2015), performing work on a construction site requires space to bring in materials and equipment and perform the required work operations. A construction site may become crowded if many multiple crews and/or different trades are required to work in the same area on the project within a specified timeframe (Nnaji 2015). The size and location of the work area available may also increase or decrease the extent of crowding experienced on a project.

**ix. Coordination:**

The process of construction to complete a project requires a high level of coordination through both the design and construction phases (Hossain 2008). Design coordination in the construction industry is crucial to project success because it eliminates potential conflict between tasks (Wang and Leite, 2016). Crowston (1994) suggested that coordination in the construction industry depends on management among tasks and resources. Also, coordination constraints are founded on the types of interdependencies between actions (Pentland 1994; Malone et al., 1993). As a consequence, coordination of the work plays a vital role in executing a construction project since it helps to reduce space and operational conflicts, and enhances teamwork and collaboration. At a task level, coordination might make executing a task more efficient. Kadefors (1995) concluded that the degree of interdependence between different tasks and subtasks required for coordination. Interdependence can be characterized as pacaged, sequential or reciprocal (Thompson 1967); thus, all of these methods of interdependence call coordination (Kadefors 1995).

### x. Value of the task:

Hendrickson (1998) noted that cost is fluid and often difficult to calculate accurately during the implementation phase of projects. All tasks on construction project have a dollar value, which may be measured by the amount of work finished, complexity, and expended labor and equipment usage. In other words, the value of a task can vary depending on the size of the project or the type of activity. To illustrate, if a task has a low value on one project, it may not be accurate to expect the same amount of value on another project. Nnaji (2015) concluded that the more amount of dollar value and complexity of a project, the more demand placed on a worker to complete the given tasks.

Nnaji (2015) also reported that all tasks on construction projects are valuable since they consume resources and contribute to completion of the project. In addition to the cost and resources used/consumed, the value of a task can vary depending on its complexity, criticality (relative to the schedule critical path), and the type and availability of labor and equipment required to complete the task. Hence, the value of a task could impact a worker's performance on a project.

### xi. Interruptions:

Interruptions causes errors. Previous research has shown that interruptions increase mistakes when performing a task (Brumby et al. 2013; Li et al. 2008; Trafton et al. 2011). Theses interruptions can be external, such as workers asking others questions, or using a mobile device. The interruptions can also be related to personal issues such as concerns about divorce (Brumby et al. 2019). As a result, interruptions can impact task performance.

Jett and George (2003) divided interruptions into four major types: intrusion, break, distraction, and discrepancy. All the types have positive and negative impacts on productivity (Tregubov et al. 2017), safety, and quality. While a worker is working on an activity, he/she may need to stop in order to talk with a fellow employee, attend to problems related to the project, replenish material stockpiles, assist an inexperienced crew member, attend to personal business, etc. The interruptions could be internal or external to the project (Nanji 2015).

**xii. Distractions**

In our everyday life, distractions are a significant factor that weaken our output. As a result, many studies have resulted in theories to measure the effect of distractions on worker performance, particularly on safety and quality. One study led to the creation a theory known as the "Distractions Theory." This theory suggests that safety is situational, meaning accidents or injuries are caused when workers are districted while performing their work tasks. According to the Distractions Theory, there are two types of distractions:

i. Jobsite hazards (unsafe physical conditions):

   Hinze (2006) states that when the hazard level is high, it is expected that the worker should be aware to the hazard; hence, the attention paid to the hazard becomes a distraction for the worker.

ii. Mental distractions:

   Workers try to perform their task according to their work plan. However, the workers might be distracted by personal problems (e.g., financial worries, pregnancy, family disputes, etc.) or job-related concerns (e.g., tight deadlines, trouble with boss, etc.) (Seevaparsaid-Mansingh and Haupt 2008). On the contrary, positive events may distract workers also, such as parties, celebrations, pay days, and going on a holiday (Hinze, 2006).

To this end, distraction could be associated with either external or internal factors. and adverse weather conditions, safety attitude/culture, location of project, excessive pressure, poor working relationship with co-workers, poor communication, work schedule, etc. are considered to be constituents of distraction of a construction worker (Nanji 2015). In addition, Nnaji defines distraction as *"while conducting their work tasks, workers may be mentally distracted by the surrounding work conditions, personal interactions with others on or off the jobsite, or other issues of concern. A distraction can be anything that inhibits workers from paying attention to the task or duty".*

**xiii. Pace of the task:**

Pace of the task is resulting from the project plan. Nanji (2015) defined pace of the task as a significant key on work execution, so "*pace of the task can be seen as time taken to get a specified amount of work done, e.g., feet per hour, cubic yard per hours, etc*." Productivity is an important factor that drives work execution. The pace of the work is considered as the time taken to perform a specified amount of work (Nanji 2015). A faster pace of work means more work is being accomplished in a given time.

**xiv. Switching between tasks:**

Previous research indicated that when a worker is required to multitask in the same period, work performance is significantly reduced (Pashler et al. 2000). Some workers may be assigned multiple tasks to perform in a given shift. In some cases, the timing of the tasks may overlap. Switching between tasks occurs when a worker attempts to go from one task to another to accomplish both tasks during the same time period. Switching may also occur when a worker is given new tasks very frequently during the work shift.

## 2.4. HUMAN PERFORMANCE

### 2.4.1. PRESSURE

Pressure can be defined in general as shown in Table 2.4.

Table 2.4: Definitions of Pressure

| No. | Definition | Source |
|---|---|---|
| 1 | *"Force per unit area."* | Nave 2014 |
| 2 | *"The continuous physical force exerted on or against an object by something in contact with it."* | oxforddictionaries.com |
| 3 | *"Force that is put on a surface with reference to the area of the surface."* | dictionary.cambridge.org |
| 4 | *"The ratio of the force applied per area covered."* | physics.info.com |

Pressure is equal to force per unit area or equal to energy per unit volume (Nave 2014), as shown in Equation 2.7:

$$\text{Pressure} = \frac{Force}{Area} \qquad \text{(Eqn. 2.7)}$$

As seen in the above equation, when the area is small, the pressure increases immediately. Nnaji (2015) converted the equation to be applied to the construction industry. Where the pressure has to do with the impact of:

Force: Construction location, size, and the number of crews (uniqueness, complexity, etc.); and

Area: Equipment present with a particular time and trades (Available time, space (location), and resources).

Therefore, work pressure increases significantly if the force (number of tasks, complexity, etc.) increases and the area (available time, space, and resources) decreases. Working under pressure and stress can influence worker performance. Napel et al. (2006) reported that working under pressure has become a routine phenomenon in the construction industry, and pressure can negatively affect worker performance of a project. Similarly, workers have to complete their work within a particular time. As result, workers might feel pressure due to production pressure by management to finish the task (e.g., being pressed to work faster), which may in turn impact work performance, such as safety, negatively (Hinze and Parker 1978; Hinze 1997; Goldenhar et al. 2003; Mitropoulos and Cupido 2009).

The impact of pressure on work performance has been studied previously as shown in Table 2.5, however such finding and knowledge have not been applied to measure or evaluate the amount of pressure felt by a worker.

Table 2.5: Studies Investigated Pressure

| **No.** | **Study** | **Authors** |
|---|---|---|
| 1 | Effective strategies for the prevention of rework. | Love et al. 2002 |
| 2 | Pressure affects worker performance and can have an impact on safety management and accident rates. | Hinze 1997; Rundmo et al. 1998; Brown et al. 2000; Mohamed 2002; Seo 2005; Mitropoulos et al. 2005 |
| 3 | Assess the effect of changes on schedule and quality performance. | Lee et al. 2005 |

| | | |
|---|---|---|
| 4 | Using cause-and-effect analysis to investigate the impact of pressure on productivity and rework. | Napel et al. 2006 |

### 2.4.2. POWER

As with energy and pressure, diverse definitions of power have been developed as shown in Table 2.6.

Table 2.6: Definitions of Power

| No. | Definition | Source |
|---|---|---|
| 1 | *"The rate at which work is performed or energy is converted ."* | Cutnell 2012 |
| 2 | *"The measure of the rate at which work is done ."* | Engineeringtoolbox.com |
| 3 | *"The rate at which work is done upon an object ."* | Physicsclassroom.com |
| 4 | *"Equivalent to an amount of energy consumed per unit time."* | Halliday et al. 2013 |

The average amount of power is the amount of work performed during a duration of time as shown in Equation 2.8:

$$\text{Average Power} = \frac{\Delta\,\text{Work}}{\Delta\,\text{Time}} \qquad \text{(Eqn. 2.8)}$$

With respect to construction worker performance of work operations, Nnaji (2015) described power (ability to do work over time) as the rate of change in energy with respect to time. Therefore, power would increase if a project's schedule is accelerated (shorter schedule). Worker performance would likely decrease gradually because of the affect that the increase in power has on project performance.

## 2.5. CONCEPTUAL OF ENERGY MODEL

For construction operations, the investigators define energy as related to performing work that involves the planning, erection, maintenance, and demolition of structures. Nnaji and Gambatese (2016) state that in previous research, the ability to carry out the work was defined as the factors, conditions, resources, and activity needed to execute work. Thus, energy as related to construction operations can be defined as a property related to the factors, conditions, and resources which exist in both the design and construction phases. Serval constituents (e.g., complexity of the task, uniqueness of the task, etc.), which will be defined in more detail below, can influence this property. These constituents may exhibit a high or low level of energy felt by workers as they perform their work.

Energy exists in several different forms. All forms of energy are either kinetic energy or potential energy. Kinetic energy is associated with motion while potential energy is associated with position (Elert 1998). According to the New Mexico Solar Energy Association (2014), there are some common forms of energy such as chemical, mechanical, electric, solar, kinetic, potential, thermal, and elastic. With respect to construction sites and operations, the form of energy that is present in construction is the physical form of energy, which can be divided into two types of energy. The two types of energy are working energy (kinetic energy) and stored energy (potential energy) (Watson 2014; US Energy Information Administration 2014).

Previous research focuses on energy through kinetic and potential energy and formulated equations for both to be applied to the construction site and construction operations. These energy terms in construction industry can be defined as:

***Kinetic Energy (KE):*** Kinetic energy is defined as the work expended in performing a task (Nnaji 2015). Kinetic energy consists of two components:

- Nature of task (NT) is a measurable total amount of the energy components that affect a work task (Nnaji and Gambatese, 2016).
- Execution of the task (ET) is a measurable total amount that reflects the energy of components linked with the dynamic execution of the work task (Nnaji and Gambatese, 2016).

***Potential Energy (PE):*** Potential energy with respect to construction work performance is defined as the effect of a task (work) on a worker that has been given to the worker to perform (Nnaji, 2015). PE is quantified using two variables:

- Demand factor (DF) signifies the energy created between the duration of the task and the time remaining to finish the task (Nnaji and Gambatese, 2016).
- The demand the complete all tasks (DCT) reflects the impact on "energy" of the relationship between the value of the work (in terms of $ or other measure) and the time available to complete the work (Nnaji and Gambatese, 2016). DCT is divided into two parts, which are the value of all tasks and the time to complete all tasks. DCT is multiplied by DF.

    i. Time to complete all tasks: Commonly in construction, each activity or project duration should be completed in a certain amount of time or a date sooner than initially scheduled (Hanna et al. 2005).

    ii. Value of tasks is the more amount of dollar value and complexity of a project, the more demand placed on a worker to complete the given tasks.

The value of the tasks can vary depending on the size of the project or the type of activity.

The expected result of this research is to validate and develop equations that consist of three levels of compositions organized in a hierarchy. These three levels of compositions are constituents, components, and metrics, respectively. Each of the level is briefly defined below:

- Constituents: Features that are used to measure a high or low level of energy.
- Components: Quantifiable factors that it can be used to measure each constituent.
- Metrics: Scales that are used to measure the degree of impact of the components.

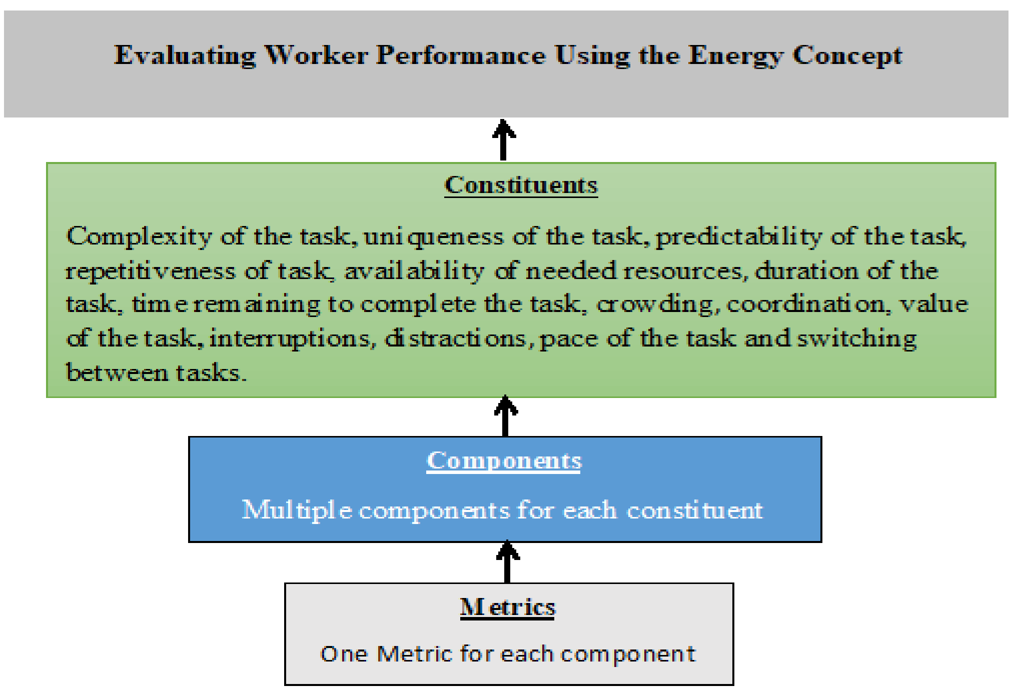



Figure 2.7: Structure of intended model to evaluate worker performance using the energy concept

The following constituents have been identified in previous research as those factors that affect the level of “energy” (i.e., combined mental and physical demand) felt by workers as they perform their work: complexity of the task, uniqueness of the task, predictability of the task, repetitiveness of the task, availability of needed resources, duration of the task, time remaining to complete the task, crowding, coordination, value of the task, interruptions, distractions, pace of the work, and switching between tasks. Table 2.7 provides a brief description of each constituent.

Table 2.7: Description of Energy Constituents

| No. | Constituent | Description |
|---|---|---|
| 1 | Complexity of the task | The mental and physical demand related with a work assignment differs from task to task. In some cases, a task is multifaceted, intricate, and complicated, and may require significant thought and special skills to perform. Tasks that are highly complex can exist on any type of project. |
| 2 | Uniqueness of the task | Some tasks required to produce a project differ from regularly-performed work and are unique to the project. Constructions employees who lack of experience may not be familiar with performing such unique tasks. |
| 3 | Predictability of the task | The construction often incorporates uncertainty in the work performed. While processes have been developed to simplify and streamline activities, some tasks associated with an activity may be unpredictable due to a lack of information about the task, a lack of requisite skills by the workers, or uncertainty about the jobsite conditions, and other work operation condition (e.g., unpredictability of the work tasks due to unknown information). |
| 4 | Repetitiveness of the task | If a task is required to be executed often by a worker, the worker will find the task to be repetitive and may feel differently about the task compared with other less repetitive tasks performed. Difference in task performance may be a result of familiarity (learning curve) developed over time. |
| 5 | Availability of needed resources | Resources (e.g., materials, equipment, labor, etc.) are a significant part of all construction projects, and resource availability is a critical factor for the work to be accomplished. |
| 6 | Duration of the task | Each task on a project is typically assigned a duration. This duration helps management verify the progress of a project. In certain cases, the prescribed duration of a task could impact the worker's performance (e.g., if the required task duration is reduced significantly to accommodate a change in project schedule). |
| 7 | Time remaining to complete the task | In most cases, workers have several tasks lined up to work on for a project. Each task should be completed within a specific duration. However, as workers approach the stipulated completion time, they could be under additional pressure due to the amount of work still to be completed within the time remaining to complete that task. |

| | | |
|---|---|---|
| 8 | Crowding | Performing work on a construction site requires space to bring in materials and equipment and perform the required work operations. A construction site may become crowded if many multiple crews and/or different trades are required to work in the same area on the project within a specified timeframe. The size and location of the work area may also increase or decrease the extent of crowding experienced on a project. |
| 9 | Coordination | Coordination of the work plays a vital role in executing a construction project since it helps to reduce space and operational conflicts, and enhances teamwork and collaboration. At a task level, coordination might make executing a task more efficient. |
| 10 | Value of the task | All tasks on construction projects are valuable since they consume resources and contribute to completion of the project. In addition to the cost and resources used/consumed, the value of a task can vary depending on its complexity, criticality (relative to the critical path), and the type and availability of labor and equipment required to complete the task. Hence, the value of a task could impact a worker's performance on a project. |
| 11 | Interruptions | While a worker is working on an activity, he/she may need to stop in order to talk with a fellow employee, attend to problems related to the project, replenish material stockpiles, assist an inexperienced crew member, attend to personal business, etc. The interruptions could be internal or external to the project. |
| 12 | Distractions | While conducting their work task, workers may be mentally distracted by the surrounding work conditions, personal interactions with others on or off the jobsite, or other issues of concern. In addition, a distraction can be anything that inhibits workers from paying attention to the task or duty. (e.g., adverse weather condition). |
| 13 | Pace of the task | Productivity is an important factor that drives work execution. The pace of the work is considered as the time taken to perform a specified amount of work. A higher pace of work means more work is being accomplished in a given period of time. |
| 14 | Switching between tasks | Some workers may be assigned multiple tasks to perform. In some cases, the timing of the tasks may overlap. Switching between tasks occurs when a worker attempts to go from one task to another to accomplish both during the same time period. Switching may also occur when a worker is given new tasks very frequently during the work shift. |

## 2.6. RESEARCH GAP

A successful construction project should meet the performance and operations requirements for safety and quality. The construction quality and safety performance consider significant key indicators in a construction project, however, a little of researchers have developed or provided methods or models for evaluating worker performance. Thus, the present research will simply further confirm the energy concept and develop it as a model for evaluating worker performance. Nnaji (2015) points out a serious need for future research to include a focus on "the evaluating safety and quality using energy concept". The core contribution of the research is to develop a model to measure the level of energy for evaluating worker performance.

One gap in existing literature pointed out by Nnaji (2015) is that the relationships between factors, namely complexity, repetitiveness, uniqueness, predictability, etc., have been developed, however, validating the composition of the relationship and deriving weights for each component related to a specific task have not yet been done. In addition, the equations previously developed need to be applied in a theatrical example and confirmed. The present research attempts to provide some suggestions for future research such as a case study could be used to display how to use previous tools and equations that on a construction project.

## 2.7. PRIMARY RESEARCH QUESTIONS

Based on the gap in knowledge related to evaluating worker performance and the energy concept as identified by the literature review, the following primary research questions remain:

1. What are the essential constituents and components, and the weighting for each, that should be measured and applied to quantify the level of "energy" experienced by a worker when conducting his/her work on a construction site?
2. What are the essential constituents that impact energy?
3. What is the relative impact of each constituent on energy?
4. How can each constituent be measured?
5. How many components are related to each constituent?
6. Can components be measured by metrics (weighting scale)?
7. Can energy be used to measure safety and quality?
8. Can a tool be created that enables application of the energy model in construction?
9. How can energy can be applied to assess safety and quality?

# 3. CHAPTER 3 – RESEARCH METHODOLOGY

## 3.1. INTRODUCTION

One key objective of this research is to develop a way to assess potential worker performance and impacts based on the level of "energy" that a worker feels when conducting his/her work. Constituents that impact the level of energy experienced, such as task complexity, repetitiveness, distractions, and pace of the work, have been identified in previous research. However, the present research is intended in part to verify and validate the energy constituents and determine the extent of their impact on the level of energy.

## 3.2. RESEARCH QUESTIONS AND HYPOTHESES

### 3.2.1. RESEARCH QUESTIONS

To successfully fulfill the research objectives, research questions should first be asked to identify what to focus on in the study. Starting with the list of research questions related to the topic that were identified in the literature review (see previous section), specific questions were selected from the list to answer in the study. The following questions are the research questions selected to be addressed by the present research:

1. What are the constituents that impact energy?
2. What is the relative impact of each constituent on energy?
3. What are the components for each constituent?
4. How can each constituent and its components be measured?
5. How can the energy model measure the level of energy?

### 3.2.2. RESEARCH HYPOTHESES

For this research, it assumed that the level of energy is a good way to measure potential worker performance, especially with respect to safety and quality on the construction site. To do so, the energy concept includes evaluating constituents of energy. In response to Research Question 1, it is hypothesized that the constituents that impact energy are:

- Complexity of the task
- Uniqueness of the task
- Predictability of the task
- Repetitiveness of the task
- Availability of needed resources
- Duration of the task
- Time remaining to complete the task
- Crowding
- Coordination
- Value of the task
- Interruptions
- Distractions
- Pace of the task
- Switching between tasks

The constituents listed above are viewed as those that impact energy because they are included in published literature. With regards to the relative impact of each constituent on energy (Research Question 2), it is hypothesized that the complexity of the task is the constituent that impacts the level of energy the greatest, while uniqueness of the task impacts the level of energy the least. The reason is that the process of a construction project is more complex, parallel, dynamic, and different than other industries (Beterslen 2004). In response to Research Question 3, it is hypothesized that the components for each constituent are provided from literature review related to these topics; safety, quality, psychology, human factors, personnel management, etc. With regards to each consistent and its components can be measured (Research Question 4), it is hypothesized that metric is categorized as a scale used to measure the degree of impact on the component while one or more components may be used to measure each constituent. In response to Research Question 5, it is hypothesized that the overall energy model could be applied to measure the level of energy associated with a task(s) on a construction site. In addition, it is believed that the energy model can be applied to a construction project to measure the level of energy to assess worker performance. The null hypothesis of the present research is that energy is not an accurate way to evaluate worker performance.  Otherwise, complexity of the task impacts energy less than uniqueness of the task. Finally, there is no relationship between energy constituents.

### 3.3. RESEARCH GOAL AND OBJECTIVES

The main aim of this research is to develop a model using “energy” to evaluate worker performance on construction sites during a project and assess an ongoing project. To meet this goal, the following objectives are the driver of this thesis:

i. Identify constituents that impact energy (Research Question #1)
ii. Identify and verify the relative impact of each constituent on energy using inputs from subject-matter experts (Research Question #2)
iii. Develop and identify components for each constituent (Research Question #3)
iv. Develop a metric for each component (Research Question #4)
v. Develop a resource that utilizes the energy model to evaluate worker performance on a construction site (Research Question #5)

A review of literature related to these topics; safety, quality, psychology, human factors, personnel management will be used to identify constituents that impact energy, develop components for each constituent and develop a metric for each component. Then, a Delphi method will be used to identify and verify the relative impact of constituents and components on energy using inputs from subject-matter experts. The relationship between research objectives to meet the research goal are shown in Figure 3.1.

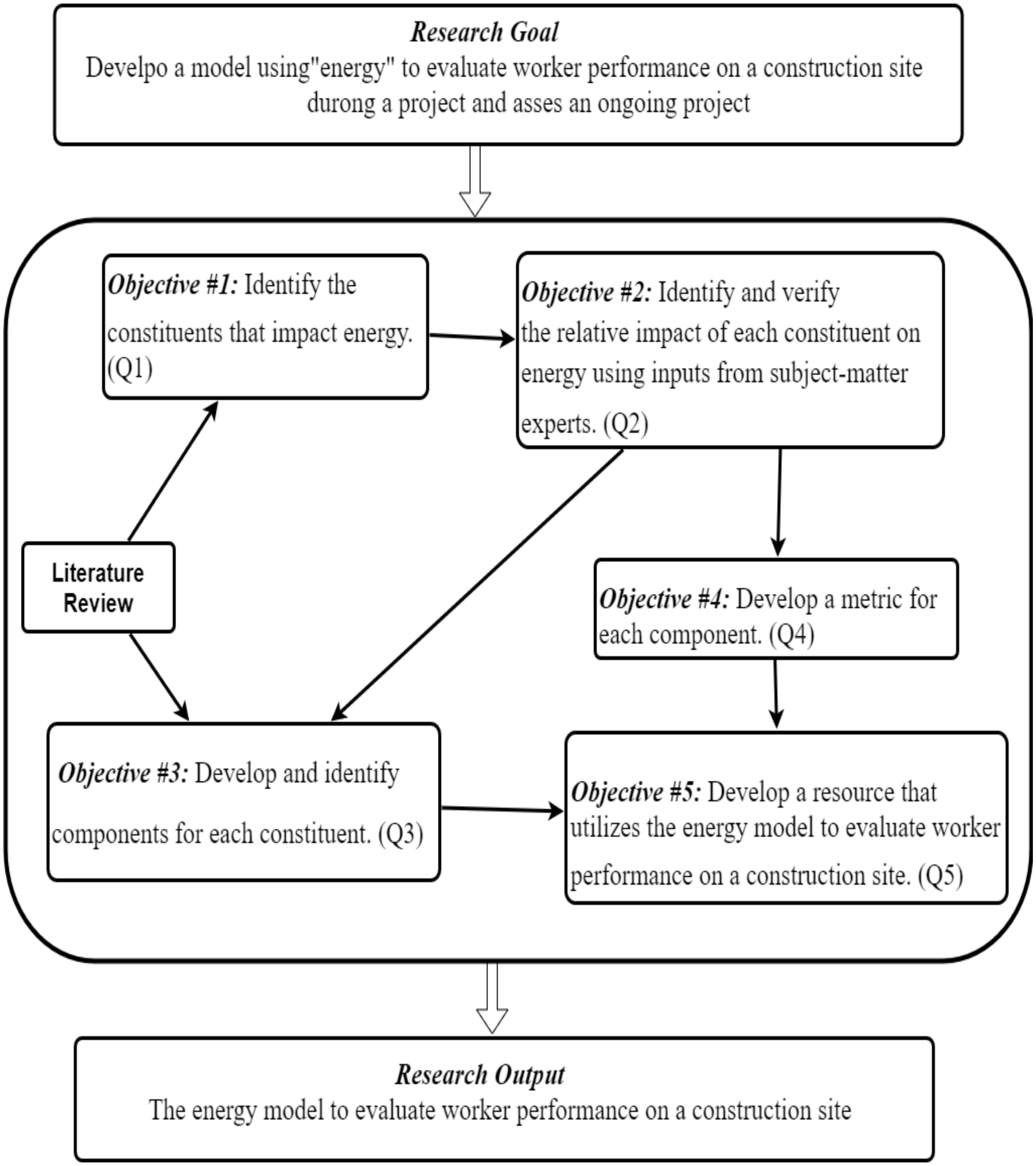


Figure 3.1: Relationship between Research Objectives

## 3.4. RESEARCH DESIGN

The researcher developed flow charts depicting the research design and research methods to exemplify the steps, participants, surveys, and procedures of this research. These flow charts, which include the stages of research, led to achieving the research objectives.

The first step for this research was to confirm energy constituents and collect data from the literature review to identify potential components for each consistent. The next phase was to develop a survey questionnaire using inputs from subject-matter experts (the Delphi process) to validate and verify the impact of each constituent on energy. After collecting the data, the researcher analyzed the data to obtain the results and prepare the energy model and tool. The literature review and Delphi process were used to collect data from both the academic and industrial fields. A description of the Delphi process is shown in Section 3.6 Data Collection. The process followed for this research is explained and discussed in different subheadings in Chapter 3 below. Figure 3.2 illustrates the research process.

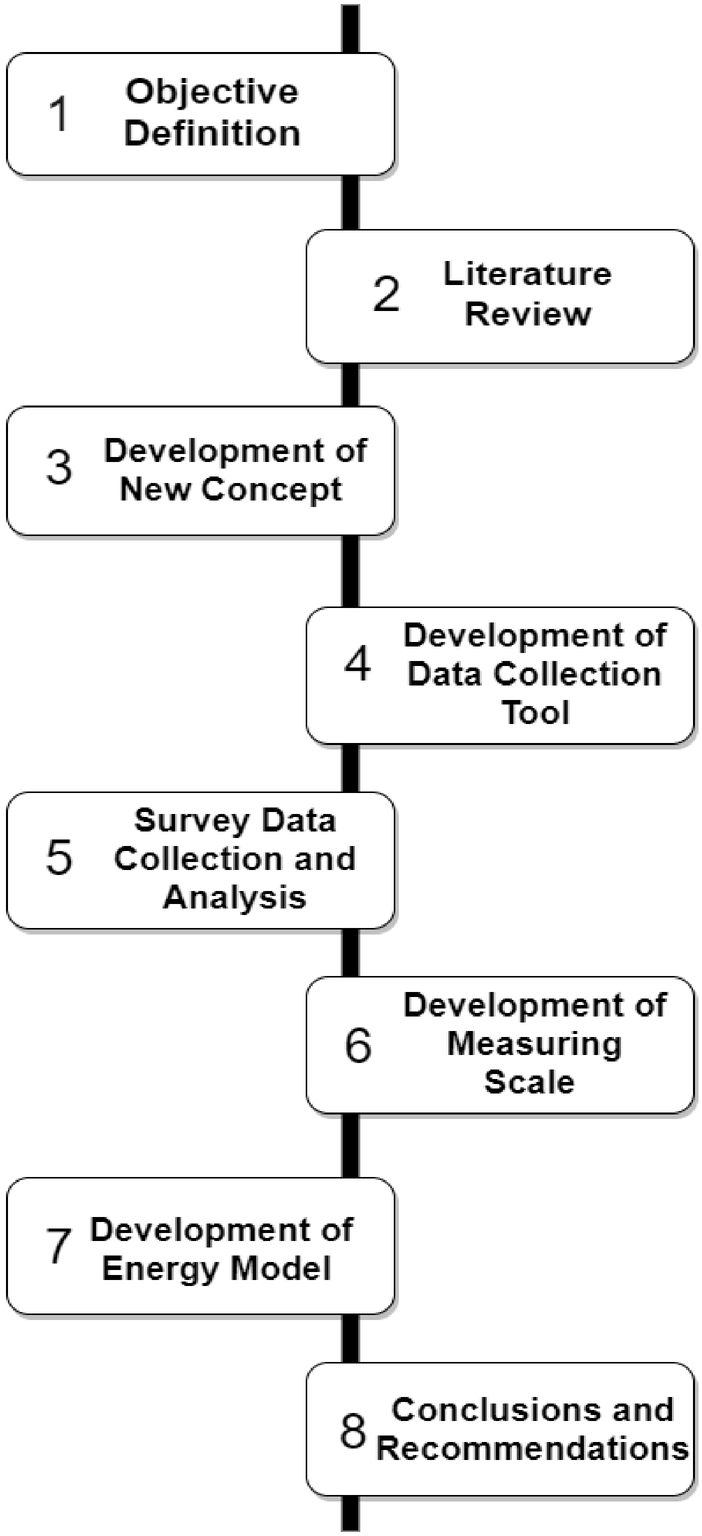



Figure 3.2: Research Process

### 3.5. METHODOLOGY

The accuracy of information is impacted by the type of information to be collected and related to the research questions, not to a specific research method (Thomas 2003; Newman and Benz 1998). To positively answer the research questions and achieve the research objectives, both quantitative and qualitative approaches were adopted in this research. It is possible that there is a lack of flexibility to use both types of the methods (Thomas 2003); however, a quantitative research method is used in this research to decrease the level of bias and to improve the quality of the statistical analysis (Bryman 1984; Creswell 2013; Jick 1979). To attain the research objectives, the following steps were planned for this research:

i. Identify constituents that impact the level of energy (Objective #1);
ii. Identify and qualify a panel of experts related to the topic of the research (Objectives #2, #3, #4).
iii. Develop a questionnaire and conduct a survey using the Delphi process to identify and verify energy constituents and components (Objectives #2, #4).
iv. Analyze quantitative survey data to develop metrics/scales for constituents (Objectives #3).
v. Develop and implement tool representing the energy model to evaluate worker performance (Objectives #5).

### 3.6. DATA COLLECTION

This research had two data collection phases, which are a literature review and an expert survey (Delphi process). These steps were selected and applied as the necessary steps to collect data for this research. The research team created the Delphi survey to determine the expert panelists and verify existing constituents and identify components for each constituent (Objectives #2, #3, #4), and expert opinion to confirm the energy model (Objective #5). Also, the research team used literature reviews and the results of previous research to find constituents and components (Objective #1, #3).

The Delphi survey was used to collect data for this research. As a first step in the Delphi process, the researcher created a list of potential expert panelists who work in industry or academia. A description of the Delphi process shown in Section 3.6 Data Collection. The final round of data collection was through the Delphi process as well to confirm the energy model and its potential use as a means to evaluate worker performance related to safety and quality. This part of the data collection was conducted after the researcher received all three rounds of the Delphi survey responses and analyzed data to create an implementation tool for application to a construction. The data collection process for this research is shown in Figure 3.3.

To achieve research objectives and answer the research questions, the data collection was broken down into two phases, which will be described in detail below:

i. Literature review
ii. Delphi method

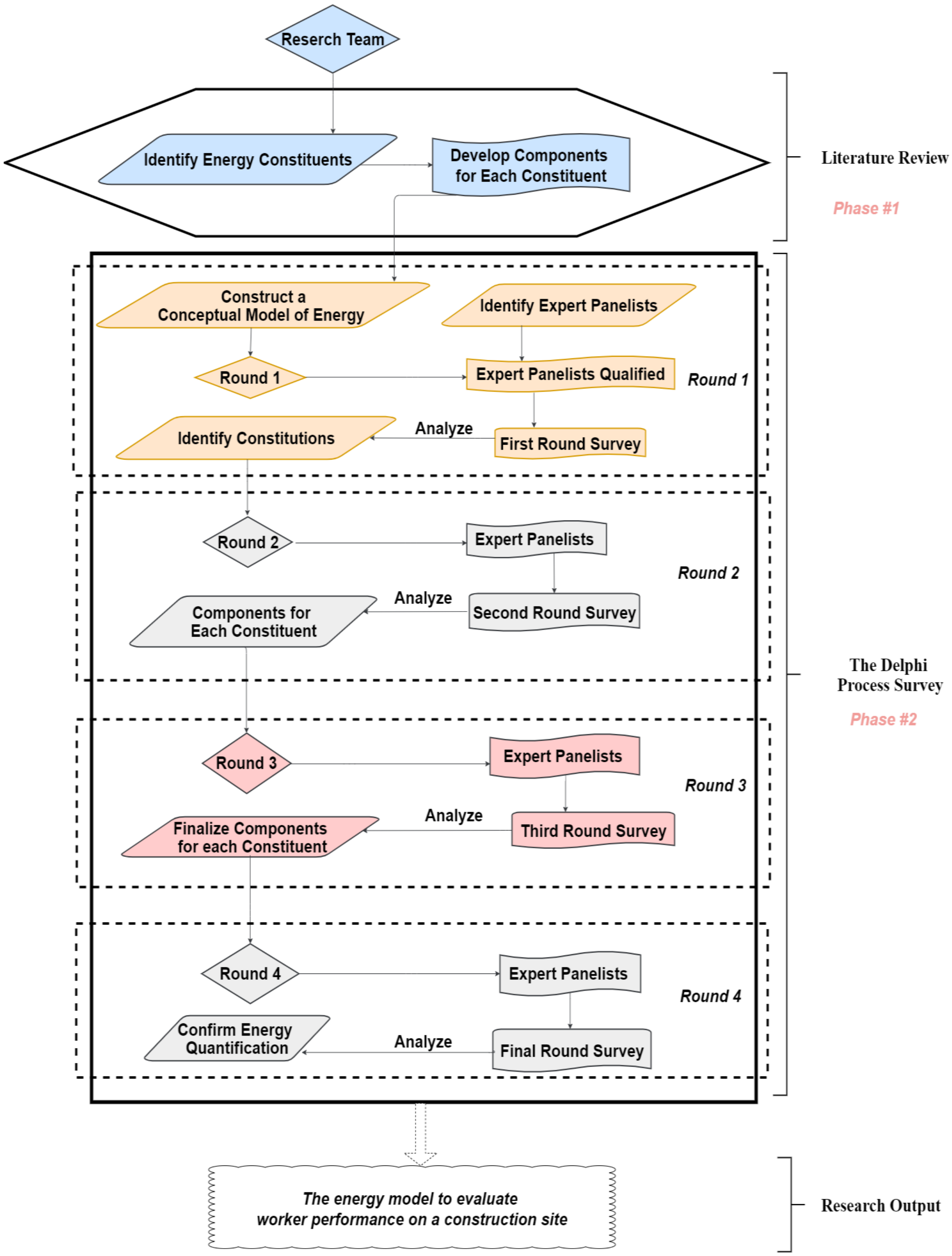



Figure 3.3: Data Collection

As highlighted in Figure 3.3, the data collection is divided into two phases. The researcher followed the steps described below to ensure the research developed and progressed at a stable pace.

### 3.6.1. PHASE #1: LITERATURE REVIEW

To achieve research Objectives #1, #3, and #4, the researcher used an extensive and wide literature review about work performance to collect components for each constituent. The literature review was related to the focus of the study (e.g., safety, quality, psychology, human factors, personnel management, etc.). Also, the researcher used a literature review to develop one metric for each component.

The researcher used a literature review to collect data to identify components and metrics to measure energy constituents. In addition, the Delphi process depended on components and metrics from that found in the literature review. Therefore, the research team started developing the survey questionnaires once they identified components for each constituent.

### 3.6.2. PHASE #2: THE DELPHI PROCESS

To develop the detailed energy model, the researcher aimed to use three perspectives: literature, input from experts, and the experience of the researchers. Therefore, the study involves obtaining information from a panel of experts in the construction industry. To gain input from experts, the researchers decided to use the Delphi method. In general, researchers utilize the Delphi methods, which is a data-collection method that relies on an expert panel to provide contextual insights and information about a topic, for verification and validation related to the topic (Hallowell and Gambatese 2010; Sierra et al. 2016).

The Delphi method is preferred to subjective research methodologies because of the ability of the Delphi process to minimize judgment-based bias, the extremely high quality of the

Delphi participants, and the ease of implementation in an increasingly global industry (Hallowell and Gambatese 2010; Sierra et al. 2016). The Delphi process includes multiple rounds of survey to achieve consensus amongst the expert panelists. Also, the Delphi method presents a technique for communication designed to obtain the maximum amount of unbiased opinion from a panel (Chan et al. 2001).

The purpose of applying the Delphi process in this research is to minimize bias and reach consensus by reducing modifications in responses and also to improve accuracy (Hallowell and Gambatese 2010). The research team designed four rounds for the Delphi process to achieve consensus through feedback. Delphi studies show that the number of rounds typically ranges from two to six rounds (Dalkey et al. 1970; Gupta and Clarke 1996; Linstone and Turoff 1975; Pill 1971).

The success of the Delphi method depends on the qualified and selected panel members and their level of expertise (Chan et al. 2001; Hallowell and Gambatese 2010). The number of panel members has ranged between three to 80 members (Rowe and Wright 1999); however, Mitchell (1991) and Hallowell and Gambatese (2010) recommend an expert panel size of 8-18 members to optimize the Delphi process. In a recent study, the research team utilized 16 panelists (Karakhan, A. A. et al. 2020). For the present study, the expected result of the Delphi process is the validation of the constituents and components of energy, and the confirmation of equations to quantify the energy. Finally, gaining expert opinion on the energy model will be performed using the Delphi process.

### 3.7. BIAS CONTROLS

The research team used the Delphi process to minimize bias in the study to achieve the highest quality results. In this study, there could be a bias that might be percent, and the types of bias are recency effect, von restorff effect, and neglect of probability (Hallowell and Gambatese 2010). The following five controls were successfully applied to this research:

i. Random selection of expert panelists

To control the bias associated with selecting expert panelists, the researcher selected the panelists randomly from the initial list of potential experts. To do so, the researcher randomly listed all of the potential experts in a table from 1-79 using a random ordering software program (https://www.random.org/). For construction risk studies, randomization of questions or selection of expert panelists can be used to reduce bias associated with the contrast, Von Restroff, and primacy effects (Hallowell and Gambatese 2010).

i. Removal of panel members who are found to not be qualified as an expert.

In part one of Round one, Delphi panel members were asked to provide their highest level of education, type of organization, their current job title, years of professional experience, professional affiliations or committee, and authorship of papers, articles, reports, and other formal publications. Using the identified criteria, the researcher evaluated each panel member to qualify them as an expert. Those who did not meet the minimum criteria were dropped from the panel. This type of control can be used to reduce bias associated with the recency effect (Hallowell and Gambatese 2010).

ii. Controlled feedback

The purpose of providing feedback to the panel after each round was to obtain more accurate results. In addition to the median, a panel member was asked to provide a brief calcification if their final ratings were two or more units away from group ratings. Hallowell and Gambatese (2010) stated that a brief of calcification should be reported as part of the controlled feedback in the next round.

iii. Conduct multiple rounds of surveys.

The Delphi process contained multiple rounds of survey. The main reason for conducting multiple rounds of surveys was to reach a high degree of consensus among the panel members. Conduct multiple rounds of surveys is essential for avoiding the impact of dominant panelists (Hallowell and Gambatese 2010). from 0-7 where:

- 0 = No Impact
- 1 = Low Impact
- 2 = Minor Impact
- 3 = Slight Impact
- 4 = Mild Impact
- 5 = Moderate Impact
- 6 = High Impact
- 7 = Extreme impact.

ii. Constituent and component ratings

The survey was structured such that panel members used a rating scale for each constituent and component from 0-7 Likert scale to reduce bias associated with the neglect of probability (Hallowell and Gambatese 2010).

iii. Report median values

The median was reported to obtain group aggregated responses associated with each constituent and component because *"median response is less likely to be affected by biased responses"* (Hallowell and Gambatese 2010).

### 3.8. IDENTIFY EXPERT PANELISTS

The study involved an expert panel knowledgeable about worker performance or related topics utilizing the Delphi process. Based on literature reviews and personal contact lists, an initial list of panelists was created of people who may be representative of experts in different fields of study related to the topic. To verify the expertise of the members of the panel, the panelists need to be qualified or involved in one of the following areas: safety, quality, psychology, human factors, personnel management, worker performance, or similar field. The expert panel involves both academic and industry personnel.

Two groups of people were involved in this research, academics (e.g., university professors) and construction industry professionals (e.g., project managers, safety engineers). The selection of potential expert panelists was divided into two steps. The first step to determine members of the panel was to solicit the consent of potential panelists to participate in the research study. An initial list of potential panelists in the academic and industrial fields was created based on the researchers' personal contact lists, authorship of journal and conference papers, the experts' position, and contacts listed on websites related to the research topic. The next step to determine the panel of experts was based on their experience and knowledge in different topics related to the topic such as worker performance, safety, quality, health, and psychology.

Based on the established criteria, the initial list for both fields contained 79 potential expert panelists (19 academics and 60 industry professionals). The researchers decided to randomly select and invite 60 expert panelists from both academia and industry to participate. The research team contacted, via email, each of the 60 people to ask about their consent to participate in the study.

To confirm that a participant is qualified as an expert or not, Hallowell and Gambatese 2010 identified criteria and allocated a point to each criterion. These criteria were used to qualify the expert panelists for the study. Hallowell and Gambatese (2010) suggested that panelists score at least 11 points to meet the minimum level of qualified expert panelists using the system point. The criteria and their points are shown in Table 3.1.

Table 3.1: Point System for Qualification of Expert Panelists [Hallowell and Gambatese (2010) adapted]

| Criterion | Points (each) |
|---|---|
| Professional affiliations or registration | 3 points for each valid registration |
| Year of professional experience | 1 point |
| Academic or industry presentation(s) | 0.5 point |
| Academic or industry publications | Book or book chapter: 4 points; academic journal paper: 2; conference paper: 1 point; industry publication: 1 point; |
| Member of a committee | 1 point |
| Number of employees and/or students supervised | 1 point to 10 employees and/or students |
| A faculty member at an accredited university | 3 points |
| Highest level of education | BS: 4 points; MS: 2 points; Ph.D.: 4 points |
| List the positions or roles related to the topic | 3 points for each the position(s) or role(s) |

### 3.9. SURVEY DESIGN

The initial scope of the survey was to further develop the model to assess the energy felt by a worker, and to ensure that the energy model can be used to assess safety and quality. This section covers the survey design. The researchers decided to use the Delphi process for this research, which had four rounds and was developed by the researchers. Since the Delphi process involves human subjects, the questionnaires had to be approved by Oregon State University's Internal Review Board (IRB). After that, the description and explanation of the research were sent via email to the panel members.

The questions for all rounds of the survey were designed using a Likert scale for the answers to enable reaching consensus within the group about the ratings for each constituent and component (West & Cannon 1988). A Microsoft Word file was used to develop the survey and distribute it to the panel members. After the initial distribution, the research team sent out a reminder email to collect the data in a short time. The questionnaires were designed to accommodate four rounds of the Delphi process, as seen in Figure 3.4.

| Round 1: Verify and Quantify Existing Energy Constituents | |
|---|---|
| A | Demographic Information |
| B | Conceptual Energy Constituents |

| Round 2: Finalize Constituents and Identify Components for Each Constituent | |
|---|---|
| A | Finalize Energy Constituents |
| B | Identify Components for Each Constituent |

| Round 3: Finalize Components for Each Component | |
|---|---|
| A | Finalize Components for Each Energy Constituent |

| Round 4: Confirm Energy Quantification and Implementing Tool | |
|---|---|
| A | Confirm Energy Quantification |
| B | Confirm Implementing Tool |

Figure 3.4: Questionnaire Design for Each Round of Delphi Survey

The objective of the four questionnaires was to obtain insight from the expert panel regarding the important constituents and components of the energy model. The results of the survey are provided and presented in tabulated and charted format in Chapter 4. Each round of the Delphi process is described below.

***Round #1:*** *Verify and Quantify Existing Energy Constituents*

This questionnaire for this round of the survey (shown in Appendix A) was designed to capture the qualifications of the expert panelists and confirm the existing constituents of energy. As noted above in Section 3.5.1.3, out of the 60 potential expert panelists, 16 panel members agreed to participate in the study. Consequently, 16 responses to the Round 1 questionnaire were collected and analyzed for the first round. This round was divided into two parts as describe below:

i. Demographic Information

This first part was designed to qualify the expert panel to be a part of the study based on different types of cercaria namely: level of education, type of organization, current job title, years of professional experience, professional affiliations or registrations, professional committees, number of employees and/or students supervised, publications, and presentation.

ii. Conceptual Energy Constituents

This part of the questionnaire asked the panel members to evaluate the existing constituents and indicate the level of impact that each of the 14 constituents has on the energy felt by a worker. Also, the panel members were asked to indicate whether the impact increases or decreases the energy for each constituent.

After identifying the existing constituents based on previous research and literature, the researcher created and distributed the first round of the Delphi survey to the 16 panel members. Once the panel members returned the Round 1 survey responses, the researcher analyzed the responses and then established and distributed the second round of the Delphi survey. The second round survey questionnaire is described below.

***Round #2:*** *Finalize Constituents and Identify Components for Each Constituent*

After receiving the Round 1 survey responses, the researchers evaluated the expert members to determine if they were qualified to participate in the study based on the criteria in Table 3.1. The questionnaire for Round 2 (shown in Appendix I) was designed to capture the consensus of Round 1 about energy constituents based on the aggregated group response. Also, Round 2 asked the panel members to suggest and categorize potential components that had been identified and developed to measure each constituent (complexity, uniqueness, predictability of task, repetitiveness of the task, availability of needed resources, duration of the task, time remaining to complete the task, crowding, coordination, value of the task, interruptions, distractions, pace, and switching between activities).

A Likert scale (from 0 to 7) was used in this round to measure the impact on each constituent. Additionally, the panel members were asked whether the impact increases or decreases energy for each component. The Round 2 survey was divided into two parts as follows:

i. Energy Constituents

The Round 1 questions asked panelists to rate the level of impact that each constituent has on the level of "energy" felt by workers when performing their work using a rating scale from 0 to 7. The objective of this part of Round 2 was to reach consensus regarding the extent to which each constituent influences worker performance. The researcher provided each panel member his/her response from Round 1, and the group aggregated responses using the median from Round #1 as a point of reference. In addition, each panel member was asked whether they want to retain his/her response, and explain if his/her final answer is two or more units away from the aggregated group response.

ii. Components for Each Constituent

The research team initially developed potential components for each constituent. The penal members were asked to provide a rating (from 0 to 7) for each component as a way to measure each constituent. The objective of these questions was to obtain a weighting for the potential components and to obtain input on whether the component increases or decreases the constituent.

***Round #3:*** *Finalize Components for Each Constituent*

After receiving the results of the Round 2 survey, the researcher established the questionnaire for Round 3 and sent it out to the expert panel by email. The main goal of Round 3 was to reach consensus regarding components and to ask the panel members about finalizing component for each constituent. The Round 3 survey was one part as described below:

i. Components of Energy Constituents

The results of Round 2 were recorded and analyzed, and confirmed components for each energy constituent noted. This part of the Round 3 survey showed the results of the Round 2 survey and allowed panel members to revise their Round 2 responses, if desired, based on the aggregated group response. The objective of this part was to reach consensus regarding the extent to which each component impacts the energy constituents.

***Round #4:*** *Confirm Energy Quantification and Implementation Tool*

The objective of this round was to confirm the energy formulas that were previously developed to calculate the level of "energy" that a worker feels when conducting work on a construction site.

i. Confirm Energy Quantification

Previous research established energy formulas in terms of Kinetic Energy (KE) and Potential Energy (PE). Each formula is composed of various energy constituents. Based on the expert panelists' work experience and involvement in the previous rounds of this survey, the panel members were asked about their agreement with the use of KE and PE to model the energy felt by works when performing work operations.

ii. Confirm Implementation Tool

This section provided the panel members the implementation tool that can be applied to measure energy associated with a construction task. The panel members were asked to confirm and evaluate the model based on their experience and knowledge.

# 4. CHAPTER 4 – RESULTS

## 4.1. INTRODUCTION

This chapter presents the qualifications of the Delphi panel members who participated in the study. The demography of the panelists is analyzed to determine whether the panel member qualifies as an expert and should be retained on the panel. Secondly, the constituents and the level of impact on energy that is felt by a worker on construction sites as they perform their work is presented. Finally, components identified from the literature review and those suggested by the panel members are introduced.

## 4.2. SUMMARY OF EXPERT PANELISTS DEMOGRAPHICS

Part 1 of the Round 1 survey questionnaire asked questions regarding the demographics of the panelists. In this regard, the following information was requested from the panel members: level of education, type of organization, current job title, years of professional experience, professional affiliations or registrations, professional committee(s), number of employees and/or students, publications, and presentations. These types of questions were designated due to the objectives of the research.

As mentioned in Section 3.5.1.3, out of a total of 60 potential experts from academia and industry, only 16 experts (14 from industry and two from academia) agreed to participate in the study. The panel members have different job titles ranging from a project manager and safety engineer to faculty member. Also, they are involved in various types of organizations, including owner organizations, construction firms, design and construction firms, and universities, as seen in Appendix $B_{1.}$

The graphical distribution of the responses from other demographic-based questions asked in Part 1 of the Round 1 survey questionnaire can be found in Figures 4.1 to 4.3.

For this research, knowing a participant's number of years of professional experience may clarify why a panel member was chosen as an expert to participate in the study. The average number of years that the panelists have worked is 18 years. Figure 4.1 shows the number of years for each member. Approximately 49% of the panel members have more than 18 years of work experience.

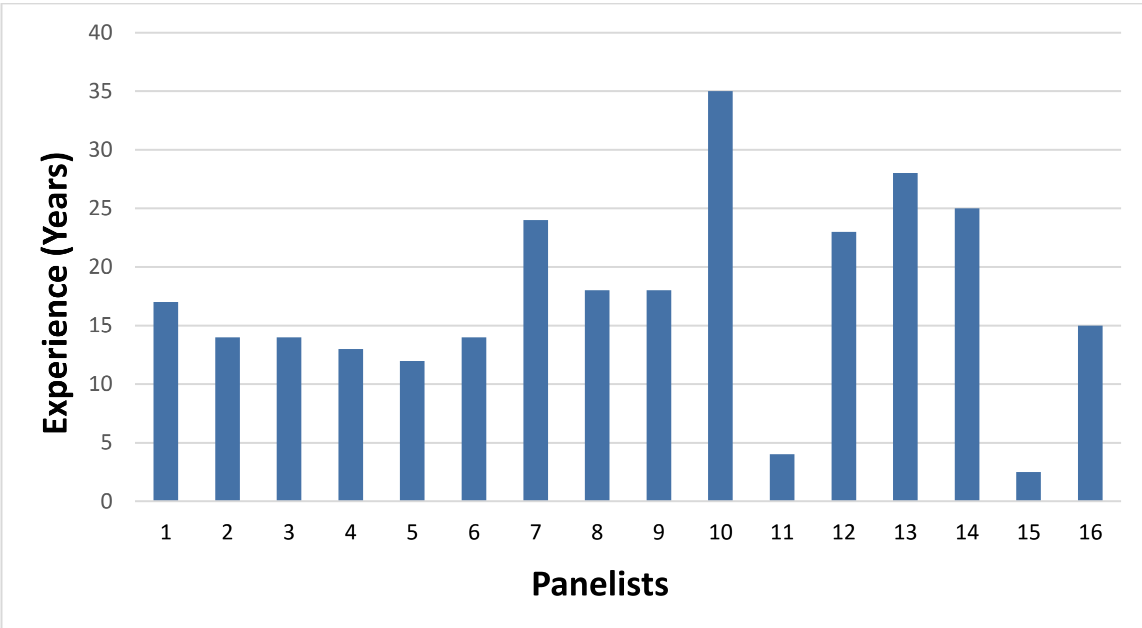



Figure 4.1:: Year of Professional Experience (n=16)

The panelists work for different types of organizations, including construction firms, universities, owner organizations, and design and construction firms. Figure 4.2 shows that the majority of panelists (11 of the 15 panelists) work for a construction firm while others work for a university, owner organization, or design and construction firm.

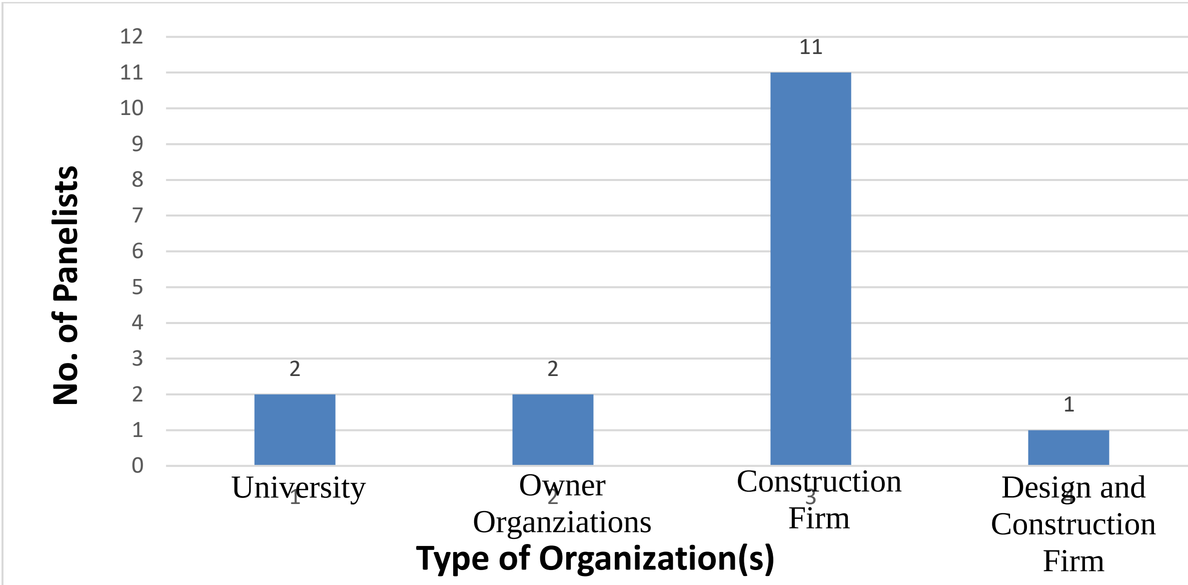



Figure 4.2: Type of Organization in which Panelists Work

As seen in Figure 4.3, most of the panelists (about 50%) are project managers and safety engineers. The other approximately 50% of panel members are divided into faculty members, project engineer, owner's representative, executive manager, design engineer, and upper management (president, COE, vice president, or other).

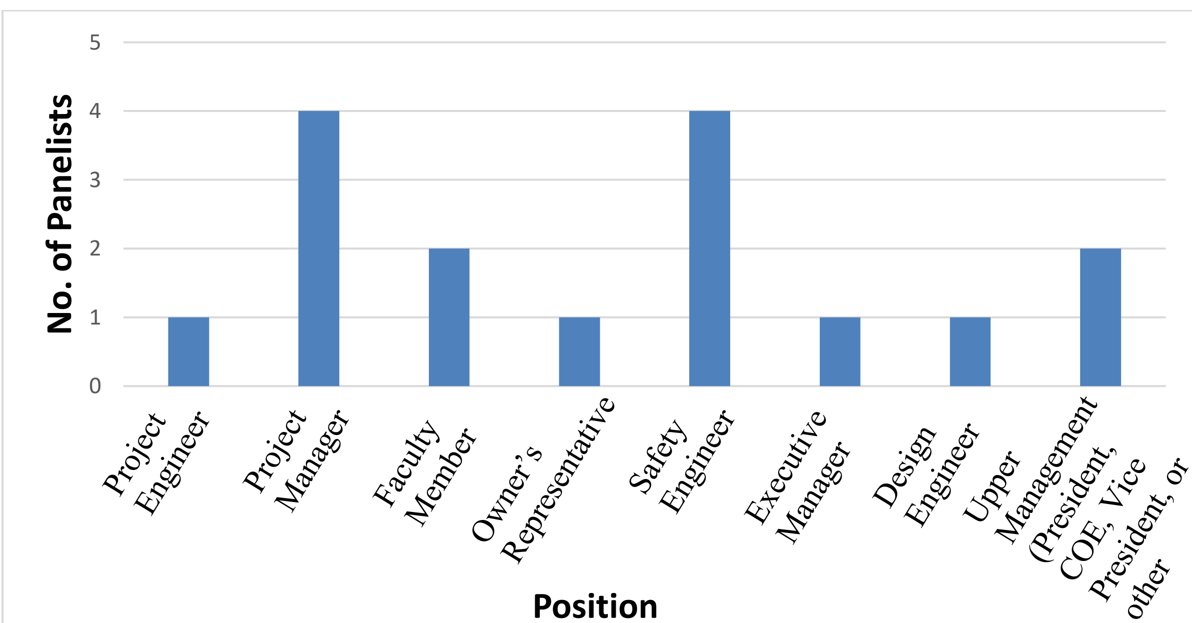



Figure 4.3: Current Job Title (Position)

As mentioned above, point values are given to each criterion to enable evaluating whether a participant is considered an expert. To be included as a participant member on the Delphi panel, the minimum number of total points should be 11 points to confidently qualify a participant as an expert (Hallowell and Gambatese 2010). The results of the qualification process for the 16 panelists who participated in the study are shown in Table 4.1. It can be seen that all expert panelists are qualified except two expert panelists (P11 and P15) who scored 6 and 7.5 points, respectively; thus, participants P11 and P15 were dropped from participation in the research.

Apart from requesting demographic information, the survey also asked about state or U.S. territory in which the panelists work. Most of the panel members work on the West Coast, while others are from all over the U.S and Canada as seen Table 4.1

.

Table 4.1: Evaluation of Qualifications of the Delphi Panel Members

| Panelists | Location (State) | Degrees | Year of Experience | Professional Registration | Member of Committee | Number of employees and/or students supervised | Publications | Presentations | Positions | Total Points |
|---|---|---|---|---|---|---|---|---|---|---|
| **P1** | Canada | 4 | 17 | 3 | - | 10 | - | 1 | 6 | 41 |
| **P1** | WA | 4 | 14 | 18 | 1 | 1.5 | 82 | 20 | 9 | 149.5 |
| **P3** | CO | 4 | 14 | 6 | 3 | 6 | 253 | 50 | 12 | 348 |
| **P4** | TX | 4 | 13 | - | - | 1 | - | 1.5 | 9 | 28.5 |
| **P5** | OR | 4 | 12 | 6 | 2 | 2.5 | - | - | 9 | 35.5 |
| **P6** | OR, WA | 4 | 14 | 6 | 1 | 150 | 4 | 10 | 9 | 198 |
| **P7** | OR | - | 24 | 6 | 4 | 11 | - | 0.5 | 6 | 51.5 |
| **P8** | CA | 4 | 18 | 3 | 1 | 100 | 4 | 10 | 6 | 146 |
| **P9** | RI | 2 | 18 | 9 | 3 | 1 | - | 1 | 6 | 40 |
| **P10** | OR | - | 35 | 3 | 1 | 4 | 1 | 1 | 12 | 57 |
| **P11** | OR, WA | 2 | 4 | - | - | - | - | - | - | 6 |
| **P12** | OR | 4 | 23 | - | - | - | - | 10 | - | 37 |
| **P13** | OR | - | 28 | 6 | 2 | 16 | - | 10 | 12 | 74 |
| **P14** | OR, WA, CA | - | 25 | - | 1 | 100 | - | - | - | 126 |
| **P15** | OR | 2 | 2.5 | - | 2 | 1 | - | - | - | 7.5 |
| **P16** | OR | 4 | 15 | 3 | 2 | 100 | - | 1.5 | 15 | 140.5 |

### 4.3. ENERGY CONSTITUENTS

The objectives of Round #1 of the survey (Appendix $A_3$) included identifying and verifying the constituents that impact energy which were identified in previous research. The panel members were asked about their level of agreement regarding whether the following constituents are factors that affect the level of "energy" (i.e., combined mental and physical demand) felt by workers as the workers perform a task: complexity of the task, uniqueness of the task, predictability of the task, repetitiveness of the task, availability of needed resources, duration of the task, time remaining to complete the task, crowding, coordination, value of the task, interruptions, distractions, pace of the task, and switching between tasks. Also, the panelists were asked to indicate their level of agreement with the following statement: The proposed conceptual energy constituents are appropriate for evaluating the level of" energy" that a worker feels in connection with his/her work on a construction site. The result was that the majority (80%) of the Delphi panel members indicated that the constituents affect the level of energy, and the energy model (implementation tool) is applicable to evaluate worker performance.

The median value of the panel's responses to each of the questions was used to determine the level of impact of each constituent on energy, while the standard deviation was used to determine whether consensus was reached amongst the panelists. Table 4.2 provides a summary of the Round #1 survey responses regarding the level of impact of the constituents. Fourteen experts participated in this round and provided responses to measure the level of impact of each constituent on the energy felt by the constituent.

Table 4.2: Panelist Responses regarding Level of Impact on Constituents on Energy (n = 14)

| No. | Constituent | Statistical Measure (0 = No impact, 7 = Extreme impact) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Median | Mean | Mode | Maximum | Minimum | SD | Range | IQR |
| 1 | Complexity of the task | 5.50 | 5.21 | 6.00 | 7.00 | 2.00 | 1.42 | 5.00 | 1.00 |
| 2 | Uniqueness of the task | 5.00 | 4.64 | 4.00 | 6.00 | 2.00 | 1.22 | 4.00 | 2.00 |
| 3 | Predictability of the task | 5.00 | 4.36 | 5.00 | 6.00 | 2.00 | 1.22 | 4.00 | 1.75 |
| 4 | Repetitiveness of the task | 5.00 | 4.36 | 5.00 | 6.00 | 2.00 | 1.28 | 4.00 | 1.00 |
| 5 | Availability of needed resources | 6.00 | 5.54 | 6.00 | 7.00 | 4.00 | 0.78 | 3.00 | 1.00 |
| 6 | Duration of the task | 5.00 | 5.14 | 5.00 | 7.00 | 3.00 | 1.23 | 4.00 | 2.00 |
| 7 | Time remaining to complete the task | 5.00 | 5.21 | 5.00 | 7.00 | 2.00 | 1.37 | 5.00 | 1.00 |
| 8 | Crowding | 5.50 | 5.07 | 6.00 | 7.00 | 3.00 | 1.44 | 4.00 | 2.00 |
| 9 | Coordination | 5.50 | 5.14 | 6.00 | 7.00 | 3.00 | 1.17 | 4.00 | 2.00 |
| 10 | Value of the task | 5.00 | 4.93 | 4.00 | 7.00 | 3.00 | 1.14 | 4.00 | 2.00 |
| 11 | Interruptions | 5.00 | 4.93 | 5.00 | 7.00 | 2.00 | 1.44 | 5.00 | 2.00 |
| 12 | Distractions | 5.00 | 4.79 | 5.00 | 7.00 | 2.00 | 1.25 | 5.00 | 1.00 |
| 13 | Pace of the task | 5.00 | 5.14 | 4.00 | 7.00 | 3.00 | 1.35 | 4.00 | 2.25 |
| 14 | Switching between tasks | 5.00 | 4.50 | 5.00 | 6.00 | 2.00 | 1.34 | 4.00 | 1.25 |

The panel members were asked to indicate whether the constituent has an increasing or decreasing impact on energy. For example, a worker's energy can be increased by the energy of fellow workers, the performance of the task, and the job duties This change in energy can be positive (increase in energy) or negative (decrease in energy). Many personal or work-related factors may impact the nature of the influence. More explanation about verification and quantification energy constituents is provided in chapter 5.

### 4.4. INITIAL LIST OF COMPONENTS FOR EACH CONSTITUENT

After the research team confirmed the constituents that impact energy based on the opinion of the expert panel, the researchers developed Round #2 of the survey to identify components for each constituent. The researchers initially identified 61 components based on the literature review, and received an additional 30 components from the Delphi panel members related to the following areas: safety, quality, psychology, human factors, personnel management, worker performance, or similar field. Appendix $B_2$ shows the 91 components that were identified from the literature review and received from the Delphi panel members.

# 5. CHAPTER 5 – ANALYSIS AND DISCUSSION

## 5.1 INTRODUCTION

Chapter 4 summarized the demographic information of the panel members and provided many energy constituents and components. In total, 14 panel members across academia and industry provided the level of impact of the energy constituents and components. This chapter of the thesis will discuss the analysis of the data extracted from the Delphi process. The following research questions will be answered in this chapter:

1. What are the constituents that impact energy?
2. What is the relative impact of each constituent on energy?
3. What are the components for each constituent?

As previously mentioned, data from 14 panel members were analyzed after going through the Delphi process. Statistical analyses of the data were then completed using Microsoft Excel to answer the research questions.

## 5.2 ANALYSIS APPROACH

The panelists indicated the impacts of the constituents and components using a 7-point Likert scale ranging from no impact (0) to extreme impact (7). A value of 5 for the median was set as the cut-off for retaining a constituent and component to quantify the level of impact of each constituent and component. One of the more challenging characteristics of the Delphi process is to reach consensus. As suggested by previous studies, the median value was used to determine the level of impact of each constituent on energy and its components (Mitchell 1991; Hallowell and Gambatese 2010). For this research, the median is less susceptible to influence by biased results; thus, median is a more accurate and appropriate measure to evaluate centrality. In addition, to measure consensus amongst the panel members, standard deviation (SD) is typically used to quantify difference from centrality (Gunhan and Arditi 2005; Hallowell and Gambatese 2010). For this study, standard deviation (SD) is used to measure consensus. An SD below 1.64 was deemed to indicate consensus, as recommended by Rogers and Lopez (2002). In addition to using the standard deviation, the Kendall's W coefficient of concordance test was used to assess consensus as recommended by Siegal (1956). In the Delphi surveys, it is possible to measure consensus using Kendall's coefficient test as recommended by Schmidt (1997) for data generated by Delphi panels to provide the degree of consensus. The value of W ranges from 0 to 1. A coefficient of 0.1 indicates very weak agreement, whereas 1 indicates strong agreement according to Schmidt (1997) and Schmidt et. al. (2001). Also, Garcia-Crespo et. al. (2010) indicated that in the nonparametric statistical approach, a weak agreement exists for $W < 0.3$; a moderate agreement is present when $W = 0.5$; and a strong agreement or consensus exists for $W >= 0.7$. As indicated in the previous research, Kendall's T coefficient can be used to find the agreement between two groups. In this research, T is calculated as zero because there is no association between two groups (Kendall and Gibbons, 1990; Schmidt 1997).

According to past studies, the research team decided that the median value was used to reach the level of impact on energy for constituents and components. Also, the standard deviation and Kendall's coefficient (W) test were utilized to measure panel consensus, as shown in Table 5.1 below.

Table 5.1: Descriptive Statistics for Research

| Measure | Constituent | Component |
|---|---|---|
| Median value (impact) | $\geq 5$ | $\geq 5$ |
| Standard deviation (consensus) | $\leq 1.64$ | $\leq 1.64$ |
| Kendall's coefficient (W) (consensus) | $\geq 0.5$ | $\geq 0.5$ |

Where:

- 0 = No Impact
- 1 = Low Impact
- 2 = Minor Impact
- 3 = Slight Impact
- 4 = Mild Impact
- 5 = Moderate Impact
- 6 = High Impact
- 7 = Extreme impact.

As seen in Table 5.1, in this research, standard deviation (SD) was used as a measurement of variability and median value was used as a measurement of central tendency. As a result, a low SD indicates that the perceived impact of the constituents and components on the energy felt by the workers tends to be close to the median value. Therefore, any constituents for which the median was less than or equal to 5 (Moderate Impact) and the SD was more than 1.64 were removed from the list. Similarly, for components, any of the components for which the median was less than or equal to 5 (Moderate Impact) and the SD was more than 1.64 were removed from the list. More specifically, the researchers decided that consensus is reached whenever the standard deviation is less than 1.64. This chapters of the thesis presents and discusses the results of the Delphi rounds. Constituents and components will be addressed separately.

## 5.3 VERIFY ENERGY CONSTITUENTS AND QUANTIFY THEIR LEVEL OF IMPACT

As previously mentioned in Chapter 4, 14 energy constituents were identified from the literature. The definitions of the constituents are shown in Table 2.7. In Round #1 and Round #2 of the Delphi process, the panel members were asked to provide the level of impact that the constituent has on the level of energy using a scale from 0-7 where 0 = No impact and 7 = Extreme impact. Also, the panel members were asked to indicate if the constituent has an increasing or decreasing impact on energy.

Fourteen responses were received and analyzed to verify and quantify existing energy constituents. The panel members agreed that the 14 constituents are an essential foundation to assess and evaluate worker performance in construction. However, some of the panel members suggested that other factors could impact energy. Also, constituents could be organized into different categories to make them more user-friendly to let project managers and supervisors focus on a specific group of constituents in order to lower the amount of energy and indicate that some constituents have a bigger impact on safety than quality. This current research did not incorporate this idea; future research could be conducted to develop the groupings. As a result, the majority (80%) of the panel members reported that the energy model is a significant and new way to evaluate worker performance (i.e., the panelists agreed with the hypothesis).

Opposing the majority, one of the panel members provided the following input, "*When I think of energy with work, I look for the most efficient way a worker can accomplish a task. For the job to run safely and successfully, the workers need to be efficient. So, I try to make their job as easy as possible by positively affecting the constituents myself*."

To quantify the level of impact of each constituent on energy to evaluate worker performance, the 14 expert panelists were asked to provide a score based on a 7-point Likert scale in Round #1. After the research team collected, analyzed, and aggregated responses from Round #1, the first part of Round #2 was to re-assess and confirm energy constituents to ensure a high level of consensus.

As suggested previously in Section 5.2, the median value ($\geq 5$) and standard deviation ($\leq 1.64$) are used to determine the level of impact and reach the level of consensus. Based on this analysis approach, responses were collected and analyzed. The level of agreement amongst the panel members ranged from 93% to 100%. Table 5.2 shows a summary of the energy constituents along with the level of impact and agreement by the expert panelists. Based on the data shown in Table 5.2, the SD for all constituents was below 1.64 and Kendall's W coefficient showed a strong level of agreement (W = 0.7); thus, consensus was reached related to the impact of the constituent.

A worker's energy can be increased by the presence of fellow workers, the performance of the job, and the job duties; this can be an increase in energy or a decrease in energy based on many factors, personal or work-related. The panel members agreed that the impact of a constituent could decrease or increase the energy depending on the situation. For instance, if many different subcontractors, workers, or crews/trades are on site at the same time, the energy felt by a worker will increase. Therefore, the Delphi panelists were asked to indicate whether each constituent increases or decreases the energy felt by the worker.

To ensure that the panel agrees with the group median for fourteen constituents. In the Round 2 survey, the panel members were asked if they agree with the results from Round 1. The Round 2 survey was distributed to the 14 panelists, as mentioned previously. Table 5.2 shows the agreement of the experts. The majority of the panelists (from 93-100%) agreed with the level of impact and effect of constituent impact on energy. To illustrate, 8 out of the 14 panelists (57%) agreed that the constituent impacts the energy. Table 5.2 summarizes the results from the Delphi method for each constituent regarding whether it has an increasing or decreasing impact on energy.

Table 5.2::Summary of constituent level of impact and weighting (n=14)

| No. | Constituent | Level of Impact (0 = no impact, 1 = low impact, 7 = extreme impact) | | | Affect of constituent impact on energy | | Weighting ($\alpha_1 - \alpha_{14}$) |
|---|---|---|---|---|---|---|---|
| | | Median | Mean | SD | Increase | Decrease | |
| 1 | Complexity of the task | 5.50 | 5.21 | 1.42 | 100% | 0% | 1.1 |
| 2 | Uniqueness of the task | 5.00 | 4.64 | 1.22 | 100% | 0% | 1.00 |
| 3 | Predictability of the task | 5.00 | 4.36 | 1.22 | 29% | 71% | 1.00 |
| 4 | Repetitiveness of the task | 5.00 | 4.36 | 1.28 | 14% | 86% | 1.00 |
| 5 | Availability of needed resources | 6.00 | 5.54 | 0.78 | 29% | 71% | 1.2 |
| 6 | Duration of the task | 5.00 | 5.14 | 1.23 | 93% | 7% | 1.00 |
| 7 | Time remaining to complete the task | 5.00 | 5.21 | 1.37 | 43% | 57% | 1.00 |
| 8 | Crowding | 5.50 | 5.07 | 1.44 | 71% | 29% | 1.1 |
| 9 | Coordination | 5.50 | 5.14 | 1.17 | 64% | 36% | 1.1 |
| 10 | Value of the task | 5.00 | 4.93 | 1.14 | 100% | 0% | 1.00 |
| 11 | Interruptions | 5.00 | 4.93 | 1.44 | 64% | 36% | 1.00 |
| 12 | Distractions | 5.00 | 4.79 | 1.25 | 64% | 36% | 1.00 |
| 13 | Pace of work | 5.00 | 5.14 | 1.35 | 93% | 7% | 1.00 |
| 14 | Switching between tasks | 5.00 | 4.50 | 1.34 | 64% | 36% | 1.00 |

The results related to each constituent for the current research are described below. Each constituent will be discussed separately.

**Complexity of the task:**

As seen in Table 5.2, all fourteen members agreed that complexity of the task impacts the energy. The median response regarding the level of impact on energy is 5.5, which indicates a moderate to a high level of impact. Also, consensus was reached as the standard deviation is 1.42. The majority of the panelists (100%) indicated that the complexity of the task constituent has an increasing impact on energy. That means, if the task is more complex, the worker will feel more energy. To found weighting of constituent relative to other constituents as seen in Table 5.2 as the median value = 5.5 as a factor to apply it to the development tool to ensure that the constituent is no less than 1.

$$\alpha_1 = \frac{\text{Constituent (Median)}}{\text{Minimum (Median)}} \quad , \qquad \alpha_1 = \frac{5.5}{5} = 1.1$$

**Uniqueness of the task**

A median value (5) was calculated as the impact score that affects the level of energy. As seen in Table 5.2, In terms of its impact on worker energy, the level of agreement of the panel members was 100%, increasing the impact on energy. These values indicate that if the task is unique, the worker will feel more energy.  The standard deviation was below 1.64; consensus was reached. Therefore, uniqueness of the task will remain as one of the energy constituents depending on the scope of the research that applies the energy formulas. The weighting of uniqueness of the task relative to other constituents, as seen in Table 5.2 shows in the equation below.

$$\alpha_2 = \frac{\text{Constituent (Median)}}{\text{Minimum (Median)}} \quad , \qquad \alpha_2 = \frac{5.00}{5.00} = 1.00$$

**Predictability of the task**

Predictability of the task is one of the fundamentals of the lean concept. As seen in Table 5.2, 93% of panelists agreed in the following values. The score of the impact of predictability of the task is 5.00 (median value). That means, the impact value is greater than or equal 5; thus, predictability of the task will remain as one of the energy constituents. The standard deviation was 1.22 $\leq$ 1.64, so consensus was reached. As a result, from the Delphi process, 71% of the panelist provided that predictability of the task has a decreasing impact on energy, while 29% of the panel members said it has an increasing impact. That means, if the task is more predictable, the worker will feel less energy. The weighting of predictability of the task relative to other constituents, as seen in Table 5.2 shows in the equation below.

$$\alpha_3 = \frac{\text{Constituent (Median)}}{\text{Minimum (Median)}} \quad , \quad \alpha_3 = \frac{5.00}{5.00} = 1.00$$

**Repetitiveness of the task**

As with uniqueness and predictability, repetitiveness of the task is estimated to have the same impact on energy. As a result of the Delphi process (Round #2), the impact value was 5; however, it was slightly deference in SD=1.28, so consensus was reached. 12 out of 14 panelists indicated that the repetitiveness of the task constituent has a decreasing impact on energy. That means, if the task is very high repetitive, the worker will feel less energy.

$$\alpha_4 = \frac{\text{Constituent (Median)}}{\text{Minimum (Median)}} \quad , \quad \alpha_4 = \frac{5.00}{5.00} = 1.00$$

**Availability of needed resources**

Availability of needed resources was the highest impact of energy constituents by 6.00 as the median value. That was provided by 14-panel members (93%) whereas one-panel member was answered differently. The consensus was reached by 0.78, which is the smallest standard deviation among constituents. Ten out 14 panelists indicated that availability of needed resources to carry out assigned tasks has a decreasing impact on energy, meaning if the worker has the correct tool to perform the task, the worker will feel less energy. To confirm that "*Better availability of needed resources will result in better work perfor*mance." (Nanij 2015).

$$\alpha_5 = \frac{\text{Constituent (Median)}}{\text{Minimum (Median)}} \quad , \quad \alpha_5 = \frac{6.00}{5.00} = 1.2$$

**Duration of the task**

Fourteen-panel members indicated that duration of the task scores 5 and 1.23 for the median value and standard deviation, respectively, so consensus was reached. As the impact on energy, 93% of panelists showed that duration of the task has an increasing impact on energy. that if the duration of the task to be completed is very short, the worker will feel more energy and more extensive pressure.

$$\alpha_6 = \frac{\text{Constituent (Median)}}{\text{Minimum (Median)}} \quad , \quad \alpha_6 = \frac{5.00}{5.00} = 1.00$$

**Time remaining to complete the task**

As seen in Table 5.2, time remaining to complete the task is scored for the level of impact as moderate impact (5), and the standard deviation is 1.37, which is below 1.64; consequently, consensus was reached. 57 % of panelists indicated that time remaining to complete the task has a decreasing impact on energy.

$$\alpha_7 = \frac{\text{Constituent (Median)}}{\text{Minimum (Median)}} \quad , \quad \alpha_7 = \frac{5.00}{5.00} = 1.00$$

**Crowding**

Crowding worksites can impact worker’s energy. As seen in Table 5.2, it is essential to note that the panel members indicated that the level of impact is 5.50 (Moderate Impact) for crowding. Also, consensus was reached below 1.64. The Delphi panelists stated that crowding has an increasing impact on energy. Crowding is considered one of the vital constituents that impact energy and therefore retains its place in the energy Equations.

$$\alpha_8 = \frac{\text{Constituent (Median)}}{\text{Minimum (Median)}} \quad , \quad \alpha_8 = \frac{5.5}{5} = 1.1$$

**Coordination**

As seen in Table 5.2, coordination has an increasing impact on energy. All panel members indicated that the impact of coordination on energy is 5.5, and consensus was reached by 1.17. As a result, from the Delphi survey, coordination increases on energy more than decreasing according to 64% of panelists. That means, the worker will feel more energy if mangers/supervisors put some effort into the amount of pre-planning. Therefore, coordination will be a part of energy formulas.

$$\alpha_9 = \frac{\text{Constituent (Median)}}{\text{Minimum (Median)}} \quad , \quad \alpha_9 = \frac{5.5}{5} = 1.1$$

**Value of the task**

All expert panelists stated that value of the task has an increasing impact on energy value, and the level of impact is 5.00 as moderator impact while one-panel member said that the value of the task has an increasing impact on energy. Consensus was reached as the standard deviation is 1.14. Hence, the value of the task will remain as a factor of energy formulas.

$$\alpha_{10} = \frac{\text{Constituent (Median)}}{\text{Minimum (Median)}} \quad , \quad \alpha_{10} = \frac{5.00}{5.00} = 1.00$$

**Interruptions**

As seen in Table 5.2, findings from Round #2 discovered that interruptions could lead to an increasing impact on energy while a worker does his/her duty. Based on the expert panelists, the impact value of interruption on energy is 5. It is also essential to reach consensus by using a standard deviation of 1.44 to keep interruption as one of the vital constituents. The worker will feel more energy if the frequency and scope of change orders are extremely significant, according to 64% of panelists.

$$\alpha_{11} = \frac{\text{Constituent (Median)}}{\text{Minimum (Median)}} \quad , \quad \alpha_{11} = \frac{5.00}{5.00} = 1.00$$

**Distractions**

Distraction has a significant impact on worker safety performance (Hinze's Distraction theory 2006, pg. 199). From the Delphi process, the distraction constituent impacts on energy as a median value is 5. Also, consensus was reached as a standard deviation of 1.25. These previous values were indicated by all panelists. According to 64% of panelists, distraction has an increasing impact on energy, meaning the worker will feel more distracted if more than weather conditions is extreme weather conditions. To confirm that, distractions create hazards that could lead to an incident that construe to poor quality of work; consequently, this is a vital constituent of energy to keep in energy equations (Nanji 2015).

$$\alpha_{12} = \frac{\text{Constituent (Median)}}{\text{Minimum (Median)}} \quad , \quad \alpha_{12} = \frac{5.00}{5.00} = 1.00$$

**Pace of the task**

Pace of the task is resulting from the project plan and scope, and it can be defined either in terms of dollars per hour or feet per hour. Panelists were agreed on an impact of the pace of the task on energy. As seen in Table 5.2, the level of impact of pace the task on energy is five, and consensus was reached to keep the impact of pace in this study. 93% of the expert panelists indicated that the pace of the task has an increasing impact on energy negatively if the task is in a massive project.

$$\alpha_{13} = \frac{\text{Constituent (Median)}}{\text{Minimum (Median)}} \quad , \quad \alpha_{13} = \frac{5.00}{5.00} = 1.00$$

**Switching between tasks**

Some activities may require a worker to switch between tasks depending on the task scheduling implementing by a supervisor. Pashler et al. 2000 proved that switching between tasks is reduced performance when a worker is required to alternate between tasks. The results from the Delphi process in this research show that switching between tasks has a degree of impact on energy with a value of 5. Also, consensus was reached from all panelists to keep switching between tasks. 64% of panelists indicated that switching between tasks has an increasing impact on energy. Therefore, switching between tasks is a vital constituent to measure the level of energy.

$$\alpha_{14} = \frac{\text{Constituent (Median)}}{\text{Minimum (Median)}} \quad , \quad \alpha_{14} = \frac{5.00}{5.00} = 1.00$$

## 5.4 IDENTIFY AND FINALIZE COMPONENTS FOR EACH CONSTITUENT

After receiving and analyzing responses in Round #2, the next step was to finalize the list of existing constituents and identify components for each constituent. As mentioned previously in Section 4.3, 91 components were found from Round #2. To shorten the list of components, Round #3 of the Delphi process asked the panelists to indicate the level of impact of each component on a constituent in order to determine whether to retain it to measure a constituent. Some components were grouped together, and the wording of some suggested components was revised, to improve clarity and maintain consistency with industry terms.

Some panelists suggested some components in their responses to the Delphi survey. Those components that were suggested were re-evaluated and compared with the literature in Round #3 to determine whether they should be included or excluded in the final list of components. That leads to if the component needs to meet all of the criteria in Table 5.1 to be retained as important to task performance, action, and execution to measure the constituent. The analysis protocol to shorten the list of 91 components was that if the component met two criteria in Table 5.1, the component remained; otherwise, the component was removed from the list of components.

The objectives of Round #3 were to finalize the list of applicable components for each constituent, assign a weighting to each component that indicates the level of impact of each component on its applicable constituent, reach consensus regarding the extent to which each component impacts the constituents, and allow all of the expert panelists to consider and evaluate the additional components suggested by some panelists during Round #2.

To achieve the stated objectives, the panelists were asked to provide a rating, using a 7-point Likert scale where 0 indicates no impact and 7 indicates extreme impact, of the level of impact of the component on the constituent. The researchers also asked the Delphi panel members to indicate the extent of the impact on the additional components suggested by the panelists in Round #2.

Out of the 14 the panel members who participated in Round #2, 13 experts completed the survey and provided responses in Round #3. If the level of impact was rated as being moderate, high, or extreme – 5, 6, or 7 on the 7-point Likert scale – based on the aggregated group median and the standard deviation was calculated to be below 1.64, the component was included in the final energy model. Otherwise, the component was removed from the list. The total number of components for each constituent can be reduced; however, if so, the level of energy calculated will be less accurate. Following this process, 38 components were removed from the list or combined with similar components because the median level of impact was rated at 4 or less and the SD was above 1.64. A total of 30 components were removed and 8 components were combined. A total of 53 components remained for inclusion in the model. The SD for all 53 components was below 1.64 and Kendall's W coefficient was calculated to be a moderate level of agreement (W= 0.5); thus, consensus was reached related to the impact of the components for each constituent.

A complete list of the components along with their level of impact is provided in Table 5.3. a weighting of the component relative to other components in the constituent. The component weighting values $X_n$ are calculated below.

$$X_n = \frac{Component_n \ (Median\ Value)}{Minimum\ Median\ Value\ (Components)}$$

Table 5.3: Summary of Components and their Level of Impact (n=13)

| Constituent | Component | Level of Impact (0-7) | | | Weighting |
|---|---|---|---|---|---|
| | | Median | Mean | SD | $X_n$ |
| 1.Complexity of the task | 1.1 Task size | 5.00 | 4.83 | 1.27 | 1.00 |
| | 1.2 Quality of pre-planning | 5.00 | 4.67 | 1.37 | 1.00 |
| | 1.3 Task execution difficulty | 5.00 | 5.00 | 0.94 | 1.00 |
| | 1.4 Number of steps/Level of accessibility | 5.00 | 5.15 | 1.14 | 1.00 |
| | 1.5 Level of physical strain/exertion | 5.00 | 4.72 | 1.19 | 1.00 |
| 2.Uniqueness of the task | 2.1 Skills/experience needed to perform the task(s) | 5.00 | 5.00 | 0.85 | 1.00 |
| | 2.2 Worker familiarity with task | 6.00 | 5.92 | 0.64 | 1.2 |
| | 2.3 Industry familiarity with task | 6.00 | 5.92 | 0.49 | 1.2 |
| | 2.4 Project/company familiarity with task | 5.50 | 5.33 | 0.98 | 1.1 |
| 3.Predictability of the task | 3.1 Level of uncertainty about task scope and performance at the start of the task | 5.00 | 5.07 | 0.95 | 1.00 |
| | 3.2 Level of uncertainty about task scope and performance during execution of the task | 5.00 | 4.84 | 1.21 | 1.00 |
| | 3.3 Predictability of task duration | 5.00 | 5.07 | 1.18 | 1.00 |
| 4.Repetitiveness of the task | 4.1 Number of times task is performed | 5.00 | 4.75 | 1.48 | 1.00 |
| | 4.2 Task duration | 5.00 | 4.63 | 1.12 | 1.00 |
| | 4.3 Task continuity | 5.00 | 4.72 | 1.61 | 1.00 |
| 5.Availability of needed resources | 5.1 Presence of materials, tools, and equipment | 6.00 | 5.69 | 1.43 | 1.2 |
| | 5.2 Quality of materials, tools, and equipment | 5.00 | 4.61 | 1.19 | 1.00 |
| | 5.3 Presence of labor force/crew members who can perform the task | 6.00 | 5.23 | 1.48 | 1.2 |
| | 5.4 Presence of capable supervisor | 5.00 | 5.15 | 1.28 | 1.00 |
| 6.Duration of the task | 6.1 Time required to complete the task | 5.00 | 5.33 | 1.30 | 1.00 |
| | 6.2 Time available to complete the task | 5.00 | 4.46 | 1.41 | 1.00 |
| | 6.3 Availability of a time buffer/contingency | 5.00 | 4.75 | 1.13 | 1.00 |
| 7.Time remaining to complete the task | 7.1 Time available to finish the remaining parts of the task | 5.00 | 5.00 | 1.41 | 1.00 |
| | 7.2 Need for overtime work to complete the task | 5.00 | 5.07 | 1.60 | 1.00 |
| | 7.3 Project completion date/Facility opening date | 6.50 | 6.55 | 0.75 | 1.3 |

| | | | | | |
|---|---|---|---|---|---|
| 8.Crowding | 8.1 Number of different subcontractors, workers, or crews/trades on site at the same time | 6.00 | 5.76 | 1.53 | 1.2 |
| | 8.2 Number of different tasks/activities in the same work area | 6.00 | 6.07 | 0.86 | 1.2 |
| | 8.3 Size of work area relative to the number of workers and size of crew present | 6.00 | 6.07 | 0.64 | 1.2 |
| | 8.4 Amount of materials and equipment present in the work area | 6.00 | 5.61 | 0.76 | 1.2 |
| | 8.5 Presence of materials and equipment in the work area | 5.00 | 4.76 | 1.09 | 1.00 |
| 9.Coordination | 9.1 Amount of pre-planning conducted | 6.00 | 6.15 | 0.68 | 1.2 |
| | 9.2 Amount of job site management of tasks | 5.00 | 5.03 | 1.29 | 1.00 |
| | 9.3 Quality of job site management/details | 6.00 | 5.92 | 0.95 | 1.2 |
| 10.Value of the task | 10.1 Value of task outcome to worker/crew | 5.00 | 4.81 | 0.75 | 1.00 |
| | 10.2 Value of the equipment/materials used for the operation | 5.00 | 4.76 | 1.36 | 1.00 |
| | 10.3 Significance of the task to the timely completion of the project (i.e., on the critical path or not) | 6.00 | 5.23 | 1.01 | 1.2 |
| | 10.4 Significance of the task to successful completion of the project | 5.00 | 5.23 | 0.83 | 1.00 |
| 11.Interruptions | 11.1 Availability of construction drawings for reference | 5.00 | 5.45 | 1.03 | 1.00 |
| | 11.2 Extent and types of interruptions | 6.00 | 5.36 | 1.02 | 1.2 |
| | 11.4 Number of overlapping work activities for crew members | 5.00 | 5.45 | 0.93 | 1.00 |
| | 11.4 Quality of detailed design drawings | 6.00 | 5.54 | 1.12 | 1.2 |
| | 11.5 Frequency and scope of change orders | 6.00 | 4.45 | 0.82 | 1.2 |
| 12.Distractions | 12.1 Experience of supervisor | 5.00 | 5.00 | 1.35 | 1.00 |
| | 12.2 Frequency of deserved positive feedback (compliments) | 5.00 | 4.75 | 1.28 | 1.00 |
| | 12.3 Night shifts | 5.00 | 5.00 | 1.41 | 1.00 |
| | 12.4 Weather conditions | 6.00 | 5.53 | 0.66 | 1.2 |
| 13.Pace of the task | 13.1 Required production rate (e.g., ft/hr, cy/hr, etc.) | 6.00 | 5.53 | 0.96 | 1.2 |
| | 13.2 Frequency of rework | 6.00 | 5.92 | 1.03 | 1.2 |
| 14.Switching between tasks | 14.1 Amount of multi-tasking required | 6.00 | 5.23 | 1.42 | 1.2 |
| | 14.2 Rate in which new tasks are given to the workers while performing current task(s) | 5.00 | 5.45 | 0.82 | 1.00 |
| | 14.3 Frequency of new workers joining the crew (due to absence, promotion, transfer, etc. of another crew member) | 5.00 | 4.85 | 1.24 | 1.00 |

### 5.5 IDENTIFY AND DEVELOP METRIC SCALE

Metric is characterized as a scale used to measure the degree of impact on the component. Weighting values will be allocated for each metric level to reflect the degree of effect on each constituent. A metric scale was developed as a linear scale for each component (e.g. 0,1,2,3,4,5). For instance, a higher weighting value will be given a higher impact. Such as if repetitiveness of the task is very repetitive, it should be given five as high impact. Using the scale 0, where 0 is "No Impact" and 5 is "High Impact," show how much impact supervisor or project manager think each crew or person has on the level of doing the following activities and the low- and high scenario observation were derived from critical judgment (BLS 1966).

To calculate the metrics scale, a methodological approach is available to assess the degree/extent of each component has given the task on any scale of measurement (i.e., 5- or 7-point scale). The degree of impact of each component on a 5-point scale where 1 indicates low impact and 5 indicates high impact (Karakhan, A. A. et al. 2020). The grades for the impact of each component are defined as [1,2,3,4, and 5], where 1 = very low, and 5 = very high (Hu et al. 2016). To end this, the users will ask to provide a rating using a scale of 1 to 5 (e.g., 1= minimal and 5= extensive) for questions that asked for qualitative input (Gambatese and Hallowell 2011).

Finally, based on the literature review, the research team was decided using a 5-point scale for the metric scale as a linear where 0= no impact, 1= negligible impact, 2= low impact, 3= mild impact, 4= medium impact and 5= high impact for the constituent that has an increasing impact on energy. On the contrary, for the constituent that has a decreasing impact on energy, the metric scale will be as 1= high impact, 2= medium impact, 3= mild impact, 4= low impact, 5= negligible impact. The reason is that if the constituent has an increasing impact on energy, it should be placed in the numerator of the equation; otherwise, it is placed in the denominator. The linear scale is a fundamental scale for this research; other different scales might conduct and test it in future studies.

### 5.6 CONFIRM AND FINALIZE ENERGY QUANTIFICATION

After developing and identifying constituents, components, and metrics, the energy model was established; however, the energy model still needed to be confirmed by the panel members. Thus, Round #4 of the Delphi survey was conducted to confirm the energy formulas that were previously developed to calculate the level of "energy" that a worker feels when conducting work on a construction site.

Each expert panelist was asked to review and confirm the energy model that was developed to calculate the level of "energy" that a worker feels when conducting work on a construction site, and answer the survey questionnaire based on their work experience and involvement in the previous rounds of the survey. The energy model calculations were provided in an Excel spreadsheet to show the panel members how the model can be applied on a construction site in the future.

Eleven Responses from 11 of the 13 panelists (84%) were received and analyzed to confirm and finalize the energy model to be applied on a construction site. The majority (80%) of those panel members who responded agreed that the overall energy model could be applied to measure the level of energy associated with a task(s) on a construction site.

The kinetic and potential energy formulas were developed in previous research (Nanij 2015), and each formula consists of different energy constituents. The panelists were asked about their agreement with the use of kinetic and potential energy to model the energy felt by workers when performing work operations. Eighty-two percent of the panelist who responded (9 experts) agreed that KE and PE can be used as a means to accurately reflect the level of "energy" experienced by workers while performing work.

Moreover, in the last round of Delphi process, the panel members were asked about constituents, components, and metrics. Eighty percent of the expert panelists agreed that the constituents can be used as a means to accurately measure the level of energy associated with a task(s) on a construction site. In addition, 73% of the panel members agreed that the components can be used as a means to accurately measure each constituent. An initial metric scale was developed for each component using a linear scale (e.g., 1, 2, 3, 4, 5). When asked about the scale, 73% of the panelists agreed that the scale values are appropriate for each level in the metric as a fundamental scale to measure each component. A construction project should meet the performance and operations requirements for safety and quality. The research team also asked the panelists whether the energy model will accurately reflect the safety performance of a worker while performing a construction task and the level of work quality produced by a worker when conducting a work task. As a result, 73% of the panelists agreed that the energy model will accurately reflect worker safety performance and work quality. Finally, the panelists were asked if the energy model can be used to accurately measure other performance criteria such as productivity, cost, etc. The result was that 7 of panelists (63%) agreed that the energy model could be used to measure other performance criteria.

# 6. CHAPTER 6 – DEVELOPMENT OF ENERGY MODEL

## 6.1 INTRODUCTION

This chapter will describe the implementation tool to measure the level of energy. The researchers used the findings from the literature review and the Delphi process to develop the energy model. Fourteen constituents and 53 components were found form the literature review and Delphi process to measure the level of energy. The development of the implementation tool will answer the following research questions:

1. How can each constituent and its components be measured?
2. How can the energy model measure the level of energy?

This chapter provides the implementation tool for applying the energy model on a construction site, as shown in Figure 6.1. An expected result of the study is to validate and develop equations that consist of three levels of compositions organized in a hierarchy. These three levels of structures are constituents, components, and metrics.

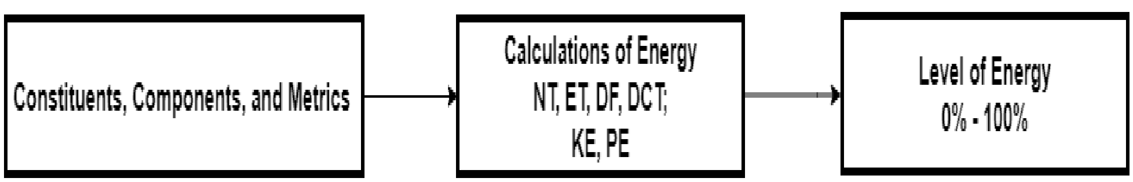



Figure 6.1: Energy Model Process

## 6.2 CONSTITUENTS

For this study, constituents refer to features that are used to measure the level of energy felt by a worker. The magnitude of the constituent may range from low to high, and the constituent may lead to an increase or decrease in the level of energy. A constituent may be defined in terms of being a part of measuring the level of energy such as complexity of the task, repetitiveness of the task, etc. The constituent value is determined by the components. Once all of the constituents are given a value based on their respective components, the values of all of the constituents are used to reveal the level of energy. The constituent value can be calculated as follows based on the components applicable to the constituent:

$$\boldsymbol{Constituent_n} = \alpha_n \times (average\ value\ of\ components) \qquad \text{(Eqn. 6.1)}$$

Where:

$$\alpha_n = \frac{Constituent_n\ (Median\ Value)}{Minimum\ Median\ Value\ (Consitiuents)} \qquad \alpha_1 - \alpha_{14} \text{ (Table 5.2)}$$

$\alpha$ : Weighting of constituent relative to other constituents

$$Average\ value\ of\ copmonents = \frac{Total\ of\ component\ values}{Number\ of\ components\ applicable\ to\ the\ constituent}$$

## 6.3 COMPONENTS

A component is defined as a feature of a task that reflects the performance, action, and/or execution of the task that can be used to assess and improve each constituent. Examples of components are: task size, number of steps to complete the task, presence of materials and tools, number of different subcontractors or crews/trades on-site at the same time, etc. Once all components for each constituent are given a value based on a Likert scale, the constituent value can be calculated. To calculate the component values, a metric should be developed first. A metric is defined as a scale that is used to measure each component. Each component has one or more metrics. The component value is calculated as follows.

$$\boldsymbol{Component_n} = X_n \times \ Metric\ value\ for\ component \qquad \text{(Eqn. 6.2)}$$

Where:

$$X_n = \frac{Component_n \ \ (Median\ Value)}{Minimum\ Median\ Value\ (Components)} \qquad X_n = 1.00, 1.1, 1.2, 1.3 \text{ (Table 5.3)}$$

n: component 1.1 to 14.5.

*X:* Weighting of the component relative to other components for the constituent

## 6.4 METRIC SCALE

A metric is defined as a scale that is used to measure the degree of impact of the component. For each metric level, weighting values are assigned to indicate the extent of the impact on each energy constituent. A metric scale has been developed for each component based on a linear scale (e.g., 0,1, 2, 3, 4, 5), as seen in Section 5.5. For example, a more significant impact will be given a higher weighting value.

## 6.5 ENERGY CALCULATIONS

In Section 2.3, the research team chose to use the formulas from previous research to measure the energy level; however, the relationship between energy constituents was modified based on the study results. Some constituents increase energy while others decrease energy as seen in Table 5.3. As a consequence, if the energy is increased by a constituent, it is included in the numerator of an equation. Otherwise, it should be put in the denominator, as shown in Equation 6.4. The following equations show how to measure the level of energy based on the constituent values,

i. ***Kinetic Energy (KE)***: Kinetic energy is viewed as the work expended in order to perform a task. KE can be calculated as follows:

$$KE = \sum_{i=1}^{n} (Nature\ of\ the\ Task)(Execution\ of\ the\ Task) \qquad \text{(Eqn. 6.3)}$$

where:

Nature of the Task (NT) reflects the inherent, internal characteristics of the task that affect the level of energy. NT is calculated as follows:

$$NT = \frac{(\text{Complexity } of\ the\ task) + (\text{Uniqueness } of\ the\ task)}{(\text{Predictability } of\ the\ task) + (\text{Repetitiveness } of\ the\ task)} \qquad \text{(Eqn. 6.4)}$$

Execution of the Task (ET) represents the external impacts resulting from the surrounding environment and chosen means and timing of the task performance. ET is calculated as follows:

$$ET = (Pace\ of\ the\ task)\left[\frac{(Crowding) + (Coordination)(Interruptions) + (Distractions) + (Switching\ between\ tasks)}{(Availability\ of\ needed\ resources)}\right] \qquad \text{(Eqn. 6.5)}$$

ii. ***Potential Energy (PE)***: Potential energy is viewed as the effect of work (a task or tasks) that has been assigned to a worker but is yet to be executed by the worker. PE can be calculated as follows:

$$PE = \left[\sum_{i=1}^{n} (Nature\ of\ Task)\right] (Demand\ to\ Complete\ All\ Tasks) \qquad \text{(Eqn. 6.6)}$$

where:

Demand to Complete All Tasks (DCT) reflects the impact on “energy” of the relationship between the value of the task and the time available to complete the task. DCT is affected by a Demand Factor (DF), which is defined below. DCT is calculated as follows:

$$DCT = \left[\frac{Value\ of\ the\ task}{Time\ remaining\ to\ complete\ the\ task}\right] (DF) \qquad \text{(Eqn. 6.7)}$$

Demand Factor (DF) represents the relationship between the duration of the task and the time remaining before the task must be completed. DF is calculated as follows:

$$Demand\ Factor\ (DF) = 1 + \frac{Duration\ of\ the\ task}{Time\ remaing\ to\ complete\ the\ task} \qquad \text{(Eqn. 6.8)}$$

After kinetic and potential energy is calculated, total energy can be calculated as follows (Boundless 2014):

$$Total\ Energy = KE + PE \qquad \text{(Eqn. 6.9)}$$

The maximum total energy that can be calculated based on a linear scale (0,1,2,3,4,5) is 875 if the values of the metric are given the highest weighting value. In contrast, the minimum total energy that can be calculated is 1 if the values of the metric are given the smallest weighting value. Therefore, Equation 6.10

$$Level\ of\ Energy = \frac{Total\ Energy}{Maximum\ Energy\ Possible} \times 100 \qquad \text{(Eqn. 6.10)}$$

will be used to find the level of energy based on the maximum total energy.

where:

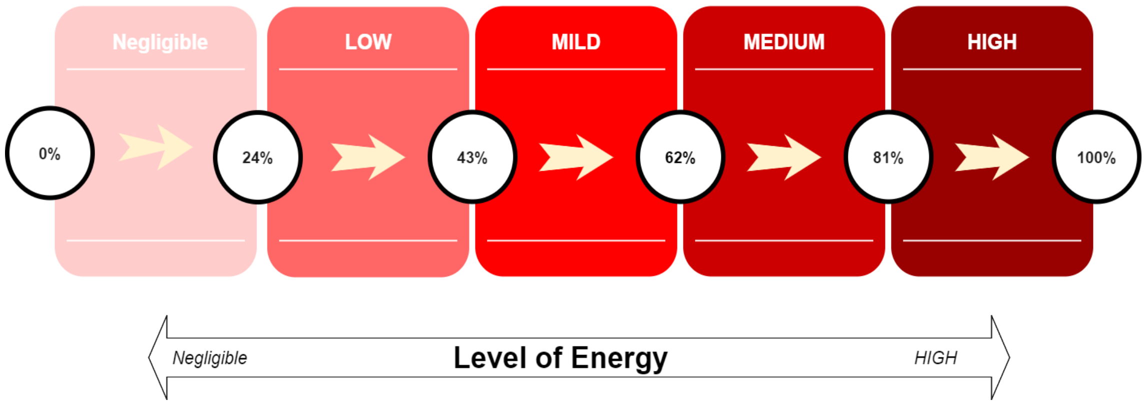
Maximum Energy Possible = 875

The level of energy ranges from 0% to 100% based on the metric values (0,1,2,3,4,5), as seen in Figure 6.2. A percentage from 0% to 24% indicates a negligible level of energy, a percentage between 25% and 43% indicates a low level of energy, a percentage from 44% to 62% indicates a mild level of energy, a percentage from 63% to 81% indicates a medium level, and a percentage between 82% and 100% indicates a high level. The percentage values of each level rely on the metric values (0,1,2,3,4,5). For example, the values of the metric are given the highest weighting value as 5 for the constituent that has an increasing impact on energy and it is included in the numerator of an equation.

The metrics that have a decreasing impact on energy are given the highest weighting value as 1 for the constituent, and therefore should be placed in the denominator of the energy equations shown above. As a result, the level of energy will be high if the metric values are given the highest weighting.

The total level of energy calculated is then evaluated based on the five ranges shown in Figure 6.2. If the level of energy is in the high range, a worker who performs the task feels more energy. Conversely, if the level of energy calculate is low (less than 24%), the amount of energy felt by a worker is negligible. Each level depends on the type of task and its scenario.

Figure 6.2: Level of Energy




After developing the equations to evaluate the level of energy, the energy model to evaluate worker performance using the energy concept is complete. The next step was to develop a tool that can be used to implement the model in practice. Table 6.1 shows the tool that will be used by users to determine metric values based on the performed task.

Table 6.1: Energy Model Implementation Tool

| Constituent | Component | Metric for Measuring Component (Linear scales: 0, 1, 2, 3, 4, 5) | Enter metric value |
|---|---|---|---|
| 1.Complexity of the task | 1.1 Task size | 5 = very large task; 4 = large task; 3 = medium-sized task; 2 = small task; 1 = very small task | |
| | 1.2 Quality of pre-planning | 5 = very poor pre-planning; 4 = poor pre-planning; 3 = fair pre-planning; 2 = good pre-planning; 1 = excellent pre-planning | |
| | 1.3 Task execution difficulty | 5 = very difficult to execute task; 4 = difficult to execute task; 3 = moderately difficult to execute task (routine manner); 2 = somewhat difficult to execute task; 1 = little difficulty to execute task | |
| | 1.4 Number of steps/Level of accessibility | 5 = extreme number of steps; 4 = high number of steps; 3 = moderate number of steps; 2 = slight number of steps; 1 = low number of steps; 0 = one step | |
| 2. Uniqueness of the task | 2.1 Skills/experience needed to perform the task(s) | 5 = extensive skills; 4 = high level of skills; 3 = moderate skills; 2 = minimal skills; 1 = little to no skills | |
| | 2.2 Worker familiarity with task | 5 = no experience; 4 = minimal experience; 3 = moderate experience; 2 = high level of experience; 1 = extensive experience | |
| | 2.3 Industry familiarity with task | 5 = not common in industry; 4 = somewhat common in industry; 3 = moderately common in industry; 2 = highly common in industry; 1 = extremely common in industry | |
| | 2.4 Project/company familiarity with task | 5 = not regularly performed; 4 = performed irregularly; 3 = performed moderately often; 2 = commonly performed; 1 = performed all the time | |
| 3. Predictability of the task | 3.1 Level of uncertainty about task scope and performance at the start of the task | 1 = very high level of uncertainty; 2 = high level of uncertainty; 3 = moderate level of uncertainty; 4 = low level of uncertainty; 5 = very low level of uncertainty | |
| | 3.2 Level of uncertainty about task scope and performance during execution of the task | 1 = very high level of uncertainty; 2 = high level of uncertainty; 3 = moderate level of uncertainty; 4 = low level of uncertainty; 5 = very low level of uncertainty | |
| | 3.3 Predictability of task duration | 1 = unpredictable task duration; 2 = low predictability of task duration; 3 = moderate predictability of task duration; 4 = high predictability of task duration; 5 = task duration certain | |
| 4. Repetitiveness of the task | 4.1 Number of times task is performed | 1 = very highly repetitive task; 2 = highly repetitive task; 3 = moderately repetitive task; 4 = low amount of repetition; 5 = non-repetitive task | |

| | | | |
|---|---|---|---|
| | 4.2 Task duration | 1 = very long task duration; 2 = long task duration; 3 = moderate task duration; 4 = short task duration; 5 = very short task duration | |
| | 4.3 Task continuity | 1 = very high level of continuity; 2 = high level of continuity; 3 = moderate level of continuity; 4 = low level of continuity; 5 = not continuous at all | |
| 5. Availability of needed resources | 5.1 Presence of materials, tools, and equipment | 1 = very low presence; 2 = low presence; 3 = moderate presence; 4 = high presence; 5 = materials, tools, and equipment present | |
| | 5.2 Quality of materials, tools, and equipment | 1 = very poor quality; 2 = poor quality; 3 = moderate quality; 4 = good quality; 5 = excellent quality | |
| | 5.3 Presence of labor force/crew members who can perform the task | 1 = very limited labor force/crew members present; 2 = low presence; 3 = moderate presence; 4 = high presence; 5 = all labor force/crew members needed are present | |
| | 5.4 Presence of capable supervisor | 1 = no capable supervisor present; 2= low presence; 3 = moderate presence; 4 = high presence; 5 = capable supervisor always present | |
| 6. Duration of the task | 6.1 Time required to complete the task | 5 = very short required time; 4 = short required time; 3 = moderate amount of required time; 2 = high amount of required time; 1 = very high amount of required time | |
| | 6.2 Time available to complete the task | 5 = very short available time; 4 = short available time; 3 = moderate amount of available time; 2 = high amount of available time; 1= very high amount of available time | |
| | 6.3 Availability of a time buffer/contingency | 5= no buffer; 4= minimal buffer; 3 = moderate buffer; 2 = high amount of buffer; 1 = extensive buffer | |
| 7. Time remaining to complete the task | 7.1 Time available to finish the remaining parts of the task | 1 = very short amount of time available; 2 = short amount of time available; 3 = moderate amount of time available; 4 = long amount of time available; 5 = very long amount of time available | |
| | 7.2 Need for overtime work to complete the task | 1 = very excessive overtime required; 2 = excessive amount of overtime required; 3 = moderate amount of overtime required; 1 = small amount of overtime required; 5 = minimal amount of overtime required | |
| | 7.3 Project completion date/Facility opening date | 1 = very short time until opening date; 2 = short time until opening date; 3 = moderate amount of time until opening date; 4= long time until opening date; 5 = very long time until opening date | |
| 8. Crowding | 8.1 Number of different subcontractors, workers, or crews/trades on site at the same time | 5 = very high number on site at the same time; 4 = many on site at the same time; 3 = moderate number on site at the same time; 2 = few on site at the same time; 1 = very few on site at the same time | |

| | | | |
|---|---|---|---|
| | 8.2 Number of different tasks/activities in the same work area | 5 = very high number in the same work area; 4 = many in the same work area; 3 = moderate number in the same work area; 2 = few in the same work area; 1 = very few in the same work area | |
| | 8.3 Size of work area relative to the number of workers and size of crew present | 5 = very small size of work area; 4= small work area; 3 = moderate size of work area; 2 = large work area; 1= very large work area | |
| | 8.4 Amount of materials and equipment present in the work area | 5 = very large amount presents in the work area; 4 = large amount presents in the work area; 3 = moderate amount presents in the work area; 2 = small amount presents in the work area; 1 = very small amount presents in the work area | |
| | 8.5 Presence of materials and equipment in the work area | 5 = very high presence in the work area; 4 = high presence in the work area; 3 = moderate presence in the work area; 2 = low presence in the work area; 1 = very low presence in the work area | |
| 9. Coordination | 9.1 Amount of pre-planning conducted | 5 = very small amount of pre-planning; 4= small amount of pre-planning; 3 = moderate amount of pre-planning; 2 = large amount of pre-planning; 1= extensive pre-planning | |
| | 9.2 Amount of job site management of tasks | 5 = very small amount of job site management; 4= small amount of job site management; 3 = moderate amount of job site management; 2 = large amount of job site management; 1= extensive job site management | |
| | 9.3 Quality of job site management/details | 5 = very poor quality of job site management/details; 4 = poor quality of job site management/details; 3 = moderate quality of job site management/details; 2 = good quality of job site management/details; 1 = excellent quality of job site management/details | |
| 10. Value of the task | 10.1 Value of task outcome to worker/crew | 5 = very high value of task outcome; 4 = high value of task outcome; 3 = moderate value of task outcome; 2 = low value of task outcome; 1 = very low value of task outcome; 0 = no value of task outcome | |
| | 10.2 Value of the equipment/materials used for the operation | 5 = very high value; 4 = high value; 3 = moderate value; 2 = low value; 1 = very low value | |
| | 10.3 Significance of the task to the timely completion of the project (i.e., on the critical path or not) | 5 = very high significance of task; 4 = high significance of task; 3 = moderate significance of task; 2 = low significance of task; 1 = very low significance of task; 0 = no significance of task | |
| | 10.4 Significance of the task to successful completion of the project | 5 = very high significance of task; 4 = high significance of task; 3 = moderate significance of task; 2 = low significance of task; 1 = very low significance of task; 0 = no significance of task | |
| 11. Interruptions | 11.1 Availability of construction drawings for reference | 5 = very low availability; 4 = low availability; 3 = moderate availability; 2 = good availability; 1 = excellent availability | |

| | | | |
|---|---|---|---|
| | 11.2 Extent and types of interruptions | 5 = very significant extent and types of interruptions; 4 = significant extent and types of interruptions; 3 = moderate extent and types of interruptions; 2 = insignificant extent and types of interruptions; 1 = very insignificant extent and types of interruptions | |
| | 11.4 Number of overlapping work activities for crew members | 5 = extreme number of overlapping activities; 4 = high number of overlapping activities; 3 = moderate number of overlapping activities; 2 = low number of overlapping activities; 1 = very low number of overlapping activities; 0 = no overlapping activities | |
| | 11.4 Quality of detailed design drawings | 5 = very poor quality; 4 = poor quality; 3 = moderate quality; 2 = good quality; 1 = excellent quality | |
| | 11.5 Frequency and scope of change orders | 5 = extremely significant frequency and scope; 4 = highly significant frequency and scope; 3 = moderately significant frequency and scope; 2 = low frequency and impact of scope; 1 = very low frequency and impact of scope; 0 = no change orders | |
| 12. Distractions | 12.1 Experience of supervisor | 5 = supervisor not experienced; 4 = minimal supervisor experience; 3 = moderate supervisor experience; 2 = highly experienced supervisor; 1 = very highly experienced supervisor | |
| | 12.2 Frequency of deserved positive feedback (compliments) | 5 = no compliments; 4 = very few compliments; 3 = moderate frequency of compliments; 2 = high frequency of compliments; 1= extensive compliments | |
| | 12.3 Night shifts | 5 = night shifts very frequent; 4 = night shifts frequent; 3 = moderate frequency of night shifts; 2 = low frequency of night shifts; 1 = very low frequency of night shifts | |
| | 12.4 Weather conditions | 5 = extreme weather conditions; 4 = significant weather conditions; 3 = moderate weather conditions; 2 = minor weather conditions; 1= minimal weather impacts | |
| 13. Pace of the task | 13.1 Required production rate (e.g., ft/hr, cy/hr, etc.) | 5 = very high production rate required; 4 = high production rate required; 3 = moderate production rate required; 2 = low production rate required; 1 = very low production rate required | |
| | 13.2 Frequency of rework | 5 = very high frequency of rework; 4 = high frequency of rework; 3 = moderate frequency of rework; 2 = low frequency of rework; 1= very low frequency of rework | |
| 14. Switching between tasks | 14.1 Amount of multi-tasking required | 5 = extensive amount of multi-tasking; 4 = high amount of multi-tasking; 3 = moderate amount of multi-tasking; 2 = low amount of multi-tasking; 1 = minimal amount of multi-tasking; 0 = no multi-tasking | |
| | 14.2 Rate in which new tasks are given to the workers while performing current task(s) | 5 = very high rate of new tasks; 4 = high rate of new tasks; 3 = moderate rate of new tasks; 2 = low rate of new tasks; 1= very low rate of new tasks; 0 = no new tasks given | |
| | 14.3 Frequency of new workers joining the crew (due to absence, promotion, transfer, etc. of another crew member) | 5 = very high frequency of new workers; 4 = high frequency of new workers; 3 = moderate frequency of new workers; 2 = low frequency of new workers; 1= very low frequency of new workers; 0 = no new workers | |

## 6.1 HYPOTHETICAL EXAMPLE

To calculate the level of energy, the constituent values should be determined first based on the component and metric values, as shown in the tables below. The example below assumes that a task has a specific value for each constituent based on the nature and execution of the task. It should be noted that this study did not collect data for the hypothetical example from an actual real-world task such as wall framing, steel installation, equipment planning, change order management, etc. The example is intended to provide an example of the implementation of the energy model and calculations. The following tables show how to measure each constituent value after the component values are determined using the metric scale. A hypothetical example of a task is given below:

> *"On a highly sensitive government industrial project worth $1 billion, a field worker is assigned to complete a task that involves installing 1500 feet of pipe. The duration assigned to this task is seven workdays, and it will cost $4,760 to install the pipe. When this task is finished, the pipefitter is expected to immediately move to a different station within the construction site and install a similar pipe system, but this time at an elevation of 15 feet above the ground. It is estimated that this second installation activity will take approximately ten days to complete. The pipefitter is paid $85 an hour."*

1- Complexity of the task

The task is very large in size for one worker and includes quality poor pre-planning. The task is routine, so the level difficulty of task execution is not a concern. The number of steps and level of physical exertion amount to an extreme number of steps and very intense exertion, respectively. Table 6.2 shows the calculations of the complexity of the task constituent value using a linear scale (e.g., 0, 1, 2, 3, 4, 5).

Table 6.2: Hypothetical Example Showing Complexity of the Task Calculations

| **Constituent** | **Component** | **Metric for Measuring Component (Linear scales: 0, 1, 2, 3, 4, 5)** | **Enter metric value** | **$X_n$= weight of component** | **Metric value × $X_n$** |
|---|---|---|---|---|---|
| 1.Complexity of the task | 1.1 Task size | 5 = very large task; 4 = large task; 3 = medium-sized task; 2 = small task; 1 = very small task | 5 | 1.00 | 5 |
| | 1.2 Quality of pre-planning | 5 = very poor pre-planning; 4 = poor pre-planning; 3 = fair pre-planning; 2 = good pre-planning; 1 = excellent pre-planning | 5 | 1.00 | 5 |
| | 1.3 Task execution difficulty | 5 = very difficult to execute task; 4 = difficult to execute task; 3 = moderately difficult to execute task (routine manner); 2 = somewhat difficult to execute task; 1 = little difficulty to execute task | 3 | 1.00 | 3 |
| | 1.4 Number of steps/Level of accessibility | 5 = extreme number of steps; 4 = high number of steps; 3 = moderate number of steps; 2 = slight number of steps; 1 = low number of steps; 0 = one step | 5 | 1.00 | 5 |

| | | | | | |
|---|---|---|---|---|---|
| | 1.5 Level of physical strain/exertion | 5 = extreme exertion; 4 = very intense exertion; 3 = moderate exertion; 2 = some exertion; 1 = light exertion; 0 = no exertion at all | 4 | 1.00 | 4 |
| | | | | ***Total value of components*** | 22 |
| | | | | ***Average value of components*** | 4.4 |

**Complexity of the task** = $\alpha_1 \times average\ value\ of\ components$ $\alpha_1 = 1.1$

**Complexity of the task =** $1.1 \times 4.4 = 4.84$

2- Uniqueness of the task

Skills needed to perform the task should be a moderate skill level; however, the worker who performs the task is not familiar with the task, whereas the work to install the pipe is performed moderately often by the company. Table 6.3 shows the calculations of the uniqueness of the task constituent value using the metric scales.

Table 6.3: Hypothetical Example Showing Uniqueness of the Task Calculations

| Constituent | Component | Metric for Measuring Component (Linear scales: 0, 1, 2, 3, 4, 5) | Enter metric value | $X_n$= weight of component | Metric value × $X_n$ |
|---|---|---|---|---|---|
| 2.Uniqueness of the task | 2.1 Skills/experience needed to perform the task(s) | 5 = extensive skills; 4 = high level of skills; 3 = moderate skills; 2 = minimal skills; 1 = little to no skills | 3 | 1.00 | 3 |
| | 2.2 Worker familiarity with task | 5 = no experience; 4 = minimal experience; 3 = moderate experience; 2 = high level of experience; 1 = extensive experience | 5 | 1.2 | 6 |
| | 2.3 Industry familiarity with task | 5 = not common in industry; 4 = somewhat common in industry; 3 = moderately common in industry; 2 = highly common in industry; 1 = extremely common in industry | 4 | 1.2 | 4.8 |
| | 2.4 Project/company familiarity with task | 5 = not regularly performed; 4 = performed irregularly; 3 = performed moderately often; 2 = commonly performed; 1 = performed all the time | 3 | 1.1 | 3.3 |
| | | | | ***Total value of components*** | 17.1 |
| | | | | ***Average value of components*** | 4.28 |

**Uniqueness of the task** = $\alpha_2 \times average\ value\ of\ components$ $\quad \alpha_2 = 1.00$

**Uniqueness of the task** = 1.00 × 4.28 = 4.28

3- Predictability of the task

The task has a very high level of uncertainty about task scope and performance at the start of the task and a very high level of uncertainty about task scope and performance during execution of the task. Also, the predictability of task duration not very high (i.e., it is unpredictable). The predictability of the task constituent value can be calculated as seen in Table 6.4.

Table 6.4: Hypothetical Example Showing Predictability of the Task Calculations

| Constituent | Component | Metric for Measuring Component (Linear scales: 0, 1, 2, 3, 4, 5) | Enter metric value | $X_n$= weight of component | Metric value × $X_n$ |
|---|---|---|---|---|---|
| 3.Predictability of the task | 3.1 Level of uncertainty about task scope and performance at the start of the task | 1 = very high level of uncertainty; 2 = high level of uncertainty; 3 = moderate level of uncertainty; 4 = low level of uncertainty; 5 = very low level of uncertainty | 1 | 1.00 | 1 |
| | 3.2 Level of uncertainty about task scope and performance during execution of the task | 1 = very high level of uncertainty; 2 = high level of uncertainty; 3 = moderate level of uncertainty; 4 = low level of uncertainty; 5 = very low level of uncertainty | 1 | 1.00 | 1 |
| | 3.3 Predictability of task duration | 1 = unpredictable task duration; 2 = low predictability of task duration; 3 = moderate predictability of task duration; 4 = high predictability of task duration; 5 = task duration certain | 1 | 1.00 | 1 |
| | | | | ***Total value of components*** | 3 |
| | | | | ***Average value of components*** | 1 |

**Predictability of the task** = $\alpha_3 \times \mathit{average\ value\ of\ components}$ $\alpha_3 = 1.00$

**Predictability of the task** = 1.00 × 1 = 1

4- Repetitiveness of the task

The task is very highly repetitive and has a very long task duration. In addition, the task has a very high level of continuity. The calculation of the repetitiveness of the task constituent value is shown in Table 6.5 using metric values such as 1 as a higher impact value.

Table 6. 5: Hypothetical Example Showing Predictability of the Task Calculations

| **Constituent** | **Component** | **Metric for Measuring Component (Linear scales: 0, 1, 2, 3, 4, 5)** | **Enter metric value** | **$X_n$= weight of component** | **Metric value × $X_n$** |
|---|---|---|---|---|---|
| 4.Repetitiveness of the task | 4.1 Number of times task is performed | 1 = very highly repetitive task; 2 = highly repetitive task; 3 = moderately repetitive task; 4 = low amount of repetition; 5 = non-repetitive task | 1 | 1.00 | 1 |
| | 4.2 Task duration | 1 = very long task duration; 2 = long task duration; 3 = moderate task duration; 4 = short task duration; 5 = very short task duration | 1 | 1.00 | 1 |
| | 4.3 Task continuity | 1 = very high level of continuity; 2 = high level of continuity; 3 = moderate level of continuity; 4 = low level continuity; 5 = not continuous at all | 1 | 1.00 | 1 |
| | | | | ***Total value of components*** | 3 |
| | | | | ***Average value of components*** | 1 |

**Repetitiveness of the task** = $\alpha_4 \times average\ value\ of\ components$  $\alpha_4 = 1.00$

**Repetitiveness of the task** = 1.00 × 1 = 1

5- Availability of needed resources

The presence of materials, tools, and equipment and the presence of a capable supervisor are low while the worker performs the task. The quality of materials, tools, and equipment is very poor. Also, the presence of crew members who can perform the task is very limited. The availability of needed resources constituent value can be measured as seen in Table 6.6.

Table 6.6: Hypothetical Example Showing Availability of Needed Resources Calculations

| **Constituent** | **Component** | **Metric for Measuring Component (Linear scales: 0, 1, 2, 3, 4, 5)** | **Enter metric value** | **$X_n$= weight of component** | **Metric value × $X_n$** |
|---|---|---|---|---|---|
| 5.Availability of needed resources | 5.1 Presence of materials, tools, and equipment | 1 = very low presence; 2 = low presence; 3 = moderate presence; 4 = high presence; 5 = materials, tools, and equipment present | 2 | 1.2 | 2.4 |
| | 5.2 Quality of materials, tools, and equipment | 1 = very poor quality; 2 = poor quality; 3 = moderate quality; 4 = good quality; 5 = excellent quality | 1 | 1.00 | 1 |
| | 5.3 Presence of labor force/crew members who can perform the task | 1 = very limited labor force/crew members present; 2 = low presence; 3 = moderate presence; 4 = high presence; 5 = all labor force/crew members needed are present | 1 | 1.2 | 1.2 |
| | 5.4 Presence of capable supervisor | 1 = no capable supervisor present; 2= low presence; 3 = moderate presence; 4 = high presence; 5 = capable supervisor always present | 2 | 1.00 | 2 |
| | | | | ***Total value of components*** | 6.6 |
| | | | | ***Average value of components*** | 1.65 |

**Availability of needed resources** = $\alpha_5 \times average\ value\ of\ components$ $\alpha_5 = 1.2$

**Availability of needed resources =** $1.2 \times 1.65 = 1.98$

6- Duration of the task

In this example, the time required to complete the task is short and there is no availability of a time buffer; however, the worker has a moderate amount of time available to complete the task. Table 6.7 shows the calculation of the duration of the task constituent value.

Table 6.7: Hypothetical Example Showing Duration of the Task Calculations

| **Constituent** | **Component** | **Metric for Measuring Component (Linear scales: 0, 1, 2, 3, 4, 5)** | **Enter metric value** | **$X_n$= weight of component** | **Metric value $\times$ $X_n$** |
|---|---|---|---|---|---|
| 6.Duration of the task | 6.1 Time required to complete the task | 5 = very short required time; 4 = short required time; 3 = moderate amount of required time; 2 = high amount of required time; 1 = very high amount of required time | 4 | 1.00 | 4 |
| | 6.2 Time available to complete the task | 5 = very short available time; 4 = short available time; 3 = moderate amount of available time; 2 = high amount of available time; 1= very high amount of available time | 3 | 1.00 | 3 |
| | 6.3 Availability of a time buffer/contingency | 5= no buffer; 4= minimal buffer; 3 = moderate buffer; 2 = high amount of buffer; 1 = extensive buffer | 5 | 1.00 | 5 |
| | | | | ***Total value of components*** | 12 |
| | | | | ***Average value of components*** | 4 |

**Duration of the task** = $\alpha_6 \times average\ value\ of\ components$ $\alpha_6 = 1.00$

**Duration of the task =** $1.00 \times 4 = 4$

7- Time remaining to complete the task

The amount of time available to finish the remaining parts of the task is very short. The task needs an excessive amount of overtime work to complete the task because it is a very short time until the project completion date when the facility needs to be open. To calculate the time remaining to complete the task constituent value, the metric values are shown in Table 6.8.

Table 6.8: Hypothetical Example Showing Time Remaining to Complete the Task Calculations

| Constituent | Component | Metric for Measuring Component (Linear scales: 0, 1, 2, 3, 4, 5) | Enter metric value | $X_n$= weight of component | Metric value $\times$ $X_n$ |
|---|---|---|---|---|---|
| 7.Time remaining to complete the task | 7.1 Time available to finish the remaining parts of the task | 1 = very short amount of time available; 2 = short amount of time available; 3 = moderate amount of time available; 4 = long amount of time available; 5 = very long amount of time available | 1 | 1.00 | 1 |
| | 7.2 Need for overtime work to complete the task | 1 = very excessive overtime required; 2 = excessive amount of overtime required; 3 = moderate amount of overtime required; 1 = small amount of overtime required; 5 = minimal amount of overtime required | 1 | 1.00 | 1 |
| | 7.3 Project completion date/Facility opening date | 1 = very short time until opening date; 2 = short time until opening date; 3 = moderate amount of time until opening date; 4= long time until opening date; 5 = very long time until opening date | 1 | 1.3 | 1 |
| | | | | ***Total value of components*** | 3 |
| | | | | ***Average value of components*** | 1 |

**Time remaining to complete the task** = $\alpha_7 \times average\ value\ of\ components$ $\alpha_7 = 1.00$

**Time remaining to complete the task =** $1.00 \times 1 = 1$

8- Crowding

The task has a large number of different subcontractors, workers, or crews/trades on site at the same time and a moderate number of tasks/activities in the same work area. The size of work area is very small relative to the number of workers and size of crew present. Also, the amount and presence of materials and equipment in the work area are very high. The crowding constituent value for the long pipe task can be calculated, as seen in Table 6.9.

Table 6.9: Hypothetical Example Showing Crowding Calculations

| **Constituent** | **Component** | **Metric for Measuring Component (Linear scales: 0, 1, 2, 3, 4, 5)** | **Enter metric value** | **$X_n$= weight of component** | **Metric value × $X_n$** |
|---|---|---|---|---|---|
| 8.Crowding | 8.1 Number of different subcontractors, workers, or crews/trades on site at the same time | 5 = very high number on site at the same time; 4 = many on site at the same time; 3 = moderate number on site at the same time; 2 = few on site at the same time; 1 = very few on site at the same time | 4 | 1.2 | 4.8 |
| | 8.2 Number of different tasks/activities in the same work area | 5 = very high number in the same work area; 4 = many in the same work area; 3 = moderate number in the same work area; 2 = few in the same work area; 1 = very few in the same work area | 3 | 1.2 | 3.6 |
| | 8.3 Size of work area relative to the number of workers and size of crew present | 5 = very small size of work area; 4= small work area; 3 = moderate size of work area; 2 = large work area; 1= very large work area | 5 | 1.2 | 6 |
| | 8.4 Amount of materials and equipment present in the work area | 5 = very large amount presents in the work area; 4 = large amount presents in the work area; 3 = moderate amount presents in the work area; 2 = small amount presents in the work area; 1 = very small amount presents in the work area | 4 | 1.2 | 4.8 |

| | | | | | |
|---|---|---|---|---|---|
| | 8.5 Presence of materials and equipment in the work area | 5 = very high presence in the work area; 4 = high presence in the work area; 3 = moderate presence in the work area; 2 = low presence in the work area; 1 = very low presence in the work area | 4 | 1.00 | 4 |
| | | | | ***Total value of components*** | 23.2 |
| | | | | ***Average value of components*** | 4.64 |

**Crowding** = $\alpha_8 \times average\ value\ of\ components$ $\alpha_8 = 1.1$

**Crowding =** $1.1 \times 4.64 = 5.10$

9- Coordination

For this example, the coordination constituent value can be measured as seen in Table 6.10. The amount of pre-planning conducted is moderate, while the amount of job site management of tasks is minimal. The quality of job site management/details for the task is poor.

Table 6.10: Hypothetical Example Showing Coordination Calculations

| **Constituent** | **Component** | **Metric for Measuring Component (Linear scales: 0, 1, 2, 3, 4, 5)** | **Enter metric value** | **$X_n$= weight of component** | **Metric value × $X_n$** |
|---|---|---|---|---|---|
| 9.Coordination | 9.1 Amount of pre-planning conducted | 5 = very small amount of pre-planning; 4= small amount of pre-planning; 3 = moderate amount of pre-planning; 2 = large amount of pre-planning; 1= extensive pre-planning | 3 | 1.2 | 3.6 |
| | 9.2 Amount of job site management of tasks | 5 = very small amount of job site management; 4= small amount of job site management; 3 = moderate amount of job site management; 2 = large amount of job site management; 1= extensive job site management | 5 | 1.00 | 5 |
| | 9.3 Quality of job site management/details | 5 = very poor quality of job site management/details; 4 = poor quality of job site management/details; 3 = moderate quality of job site management/details; 2 = good quality of job site management/details; 1 = excellent quality of job site management/details | 4 | 1.2 | 4.8 |
| | | | | ***Total value of components*** | 13.4 |
| | | | | ***Average value of components*** | 4.46 |

**Coordination** = $\alpha_9 \times average\ value\ of\ components$ $\alpha_9 = 1.1$

**Coordination =** $1.1 \times 4.46 = 4.90$

10- Value of the task

The value of the task outcome to worker/crew and value of the equipment/materials used for the operation is moderate and high, respectively. Also, to calculate the value of the task constituent value as seen in Table 6.11, the significance of the task to the timely completion of the project is moderate, and the task has high significance to successful completion of the project.

Table 6.11: Hypothetical Example Showing Value of the Task Calculations

| **Constituent** | **Component** | **Metric for Measuring Component (Linear scales: 0, 1, 2, 3, 4, 5)** | **Enter metric value** | **$X_n$= weight of component** | **Metric value × $X_n$** |
|---|---|---|---|---|---|
| 10.Value of the task | 10.1 Value of task outcome to worker/crew | 5 = very high value of task outcome; 4 = high value of task outcome; 3 = moderate value of task outcome; 2 = low value of task outcome; 1 = very low value of task outcome; 0 = no value of task outcome | 3 | 1.00 | 3 |
| | 10.2 Value of the equipment/materials used for the operation | 5 = very high value; 4 = high value; 3 = moderate value; 2 = low value; 1 = very low value | 4 | 1.00 | 4 |
| | 10.3 Significance of the task to the timely completion of the project (i.e., on the critical path or not) | 5 = very high significance of task; 4 = high significance of task; 3 = moderate significance of task; 2 = low significance of task; 1 = very low significance of task; 0 = no significance of task | 3 | 1.2 | 3.6 |
| | 10.4 Significance of the task to successful completion of the project | 5 = very high significance of task; 4 = high significance of task; 3 = moderate significance of task; 2 = low significance of task; 1 = very low significance of task; 0 = no significance of task | 4 | 1.00 | 4 |
| | | | | ***Total value of components*** | 14.6 |
| | | | | ***Average value of components*** | 3.65 |

**Value of the task** = $\alpha_{10} \times average\ vslur\ of\ components$ $\alpha_{10} = 1.00$

**Value of the task =** $1.00 \times 3.65 = 3.65$

11- Interruptions

The interruptions constituent value can be calculated, as seen in Table 6.12, based on five components. The first component is availability of construction drawings for reference, which are moderately available for this task. Also, the extent of and types of interruptions is significant, and the number of overlapping work activities for crew members is extreme. Lastly, the quality of detailed design drawings is very poor, and the frequency and scope of change orders are highly significant to the project.

Table 6.12: Hypothetical Example Showing Interruptions Calculations

| Constituent | Component | Metric for Measuring Component (Linear scales: 0, 1, 2, 3, 4, 5) | Enter metric value | $X_n$= weight of component | Metric value $\times$ $X_n$ |
|---|---|---|---|---|---|
| 11.Interruptions | 11.1 Availability of construction drawings for reference | 5 = very low availability; 4 = low availability; 3 = moderate availability; 2 = good availability; 1 = excellent availability | 3 | 1.00 | 3 |
| | 11.2 Extent and types of interruptions | 5 = very significant extent and types of interruptions; 4 = significant extent and types of interruptions; 3 = moderate extent and types of interruptions; 2 = insignificant extent and types of interruptions; 1 = very insignificant extent and types of interruptions | 4 | 1.2 | 4.8 |
| | 11.3 Number of overlapping work activities for crew members | 5 = extreme number of overlapping activities; 4 = high number of overlapping activities; 3 = moderate number of overlapping activities; 2 = low number of overlapping activities; 1 = very low number of overlapping activities; 0 = no overlapping activities | 5 | 1.00 | 5 |
| | 11.4 Quality of detailed design drawings | 5 = very poor quality; 4 = poor quality; 3 = moderate quality; 2 = good quality; 1 = excellent quality | 5 | 1.2 | 6 |

| | | | | | |
|---|---|---|---|---|---|
| | 11.5 Frequency and scope of change orders | 5 = extremely significant frequency and scope; 4 = highly significant frequency and scope; 3 = moderately significant frequency and scope; 2 = low frequency and impact of scope; 1 = very low frequency and impact of scope; 0 = no change orders | 4 | 1.2 | 4.8 |
| | | | | ***Total value of components*** | 23.6 |
| | | | | ***Average value of components*** | 4.72 |

**Interruptions =** $\alpha_{11} \times average$ value $of\ components$ $\alpha_{11} = 1.0$

**Interruptions =** $1.00 \times 4.72 = 4.72$

12- Distractions

The supervisor does not have enough experience and time to observe the worker, and there is no positive feedback given toward the worker. As the task should take approximately ten days to complete, the task is very frequently performed during the night shift. Weather condition, which has a significant impact on the project, is one of the components to measure distractions, as seen in Table 6.13.

Table 6.13: Hypothetical Example Showing Distractions Calculations

| Constituent | Component | Metric for Measuring Component (Linear scales: 0, 1, 2, 3, 4, 5) | Enter metric value | $X_n$= weight of component | Metric value × $X_n$ |
|---|---|---|---|---|---|
| 12. Distractions | 12.1 Experience of supervisor | 5 = supervisor not experienced; 4 = minimal supervisor experience; 3 = moderate supervisor experience; 2 = highly experienced supervisor; 1 = very highly experienced supervisor | 5 | 1.00 | 5 |
| | 12.2 Frequency of deserved positive feedback (compliments) | 5 = no compliments; 4 = very few compliments; 3 = moderate frequency of compliments; 2 = high frequency of compliments; 1= extensive compliments | 5 | 1.00 | 5 |
| | 12.3 Night shifts | 5 = night shifts very frequent; 4 = night shifts frequent; 3 = moderate frequency of night shifts; 2 = low frequency of night shifts; 1 = very low frequency of night shifts | 5 | 1.00 | 5 |
| | 12.4 Weather conditions | 5 = extreme weather conditions; 4 = significant weather conditions; 3 = moderate weather conditions; 2 = minor weather conditions; 1= minimal weather impacts | 4 | 1.2 | 4.8 |
| | | | | ***Total value of components*** | 19.8 |
| | | | | ***Average value of components*** | 4.95 |

**Distractions** = $\alpha_{12} \times average\ value\ \ of\ components$

**Distractions =** 1.00 × 4.95 = 4.95 $\alpha_{12} = 1.00$

13- Pace of the task

This task involves installing a 1500 ft long pipe over a very short period of time which is seven workdays; thus, the required production rate is very high required. Also, the pace of the task is measured by the frequency of rework, as seen in Table 6.14. In this example, the frequency of rework is very high.

Table 6.14: Hypothetical Example Showing Pace of the Task Calculations

| Constituent | Component | Metric for Measuring Component (Linear scales: 0, 1, 2, 3, 4, 5) | Enter metric value | $X_n$= weight of component | Metric value × $X_n$ |
|---|---|---|---|---|---|
| 13. Pace of the task | 13.1 Required production rate (e.g., ft/hr, cy/hr, etc.) | 5 = very high production rate required; 4 = high production rate required; 3 = moderate production rate required; 2 = low production rate required; 1 = very low production rate required | 5 | 1.2 | 6 |
| | 13.2 Frequency of rework | 5 = very high frequency of rework; 4 = high frequency of rework; 3 = moderate frequency of rework; 2 = low frequency of rework; 1= very low frequency of rework | 5 | 1.2 | 6 |
| | | | | ***Total value of components*** | 12 |
| | | | | ***Average value of components*** | 6 |

**Pace of the task** = $\alpha_{13} \times average\ value\ of\ components$ $\alpha_{13} = 1.00$

**Pace of the task =** $1.00 \times 6 = 6$

14- Switching between tasks

In this example, the amount of multi-tasking required is moderate, while the rate in which new tasks are given to the workers while performing the current task is a very high rate of new tasks. The frequency of new workers joining the crew (due to absence, promotion, transfer, etc. of another crew member) is one of the components used to measure the switching between tasks constituent value, as seen in Table 6.15. The frequency of new workers is high for the project.

Table 6. 15: Hypothetical Example Showing Switching between Tasks Calculations

| **Constituent** | **Component** | **Metric for Measuring Component (Linear scales: 0, 1, 2, 3, 4, 5)** | **Enter metric value** | **$X_n$= weight of component** | **Metric value × $X_n$** |
|---|---|---|---|---|---|
| 14. Switching between tasks | 14.1 Amount of multi-tasking required | 5 = extensive amount of multi-tasking; 4 = high amount of multi-tasking; 3 = moderate amount of multi-tasking; 2 = low amount of multi-tasking; 1 = minimal amount of multi-tasking; 0 = no multi-tasking | 3 | 1.2 | 3.6 |
| | 14.2 Rate in which new tasks are given to the workers while performing current task(s) | 5 = very high rate of new tasks; 4 = high rate of new tasks; 3 = moderate rate of new tasks; 2 = low rate of new tasks; 1= very low rate of new tasks; 0 = no new tasks given | 5 | 1.00 | 5 |
| | 14.3 Frequency of new workers joining the crew (due to absence, promotion, transfer, etc. of another crew member) | 5 = very high frequency of new workers; 4 = high frequency of new workers; 3 = moderate frequency of new workers; 2 = low frequency of new workers; 1= very low frequency of new workers; 0 = no new workers | 4 | 1.00 | 4 |
| | | | | ***Total value of components*** | 12.6 |
| | | | | ***Average value of components*** | 4.2 |

**Switching between tasks** = $\alpha_{14} \times average$ value $of\ components$ $\alpha_{14} = 1.00$

**Switching between tasks =** 1.00 × 4.2 = 4.2

The following equations show how to calculate the level of energy for the task after the constituent values have been calculated.

***i. Kinetic Energy (KE)*:**

$$KE = \sum_{i=1}^{n} (Nature\ of\ the\ Task)(Execution\ of\ the\ Task)$$

Where:

- Nature of the Task (NT):

$$NT = \frac{(\text{Complexity } of\ the\ task) + (\text{Uniqueness } of\ the\ task)}{(\text{Predictability } of\ the\ task) + (\text{Repetitiveness } of\ the\ task)}$$

$$NT = \frac{(4.84) + (4.28)}{(1) + (1)} = 4.56$$

- Execution of the Task (ET):

$$ET = (Pace\ of\ the\ task)\left[\frac{(Crowding) + (Coordination)(Interruptions) + (Distractions) + (Switching\ between\ tasks\ )}{(Availability\ of\ needed\ resources)}\right]$$

$$ET = (6)\left[\frac{(5.10) + (4.90) + (4.72) + (4.95) + (4.2\ )}{(1.98)}\right] = 72.33$$

$$\boldsymbol{Kinetic\ Energy}\ (\boldsymbol{KE}) = \sum_{i=1}^{n} (4.56)(72.33) = 329.84$$

The maximum level of kinetic energy is 728 based on the energy model. In this example, the energy felt by a worker in order to perform the task (kinetic energy) is 33% (329.84 / 728) of the maximum kinetic energy.

***ii. Potential Energy (PE)*:**

$$PE = \left[\sum_{i=1}^{n} (Nature\ of\ Task)\right](Demand\ to\ Complete\ All\ Tasks)$$

Where:

- Demand Factor (DF)

$$Demand\ Factor\ (DF) = 1 + \frac{Duration\ of\ the\ task}{Time\ remaing\ to\ complete\ the\ task}$$

$$Demand\ Factor\ (DF) = 1 + \frac{4}{1} = 5$$

- Demand to Complete All Tasks (DCT)

$$DCT = \left[\frac{Value\ of\ the\ task}{Time\ remaining\ to\ complete\ the\ task}\right](DF)$$

$$DCT = \left[\frac{3.65}{1}\right](5) = 18.25$$

$$\boldsymbol{Potential\ Energy\ (PE)} = \left[\sum_{i=1}^{n}(4.56)\right](18.25) = 83.22$$

The maximum level of potential energy is 147 based on the energy model. In this example, the potential energy felt by the worker is 83.22 out of 147 (57%). This represents the effect of a task on a worker that has been given to the worker to perform. After kinetic and potential energy are calculated, the total energy can be calculated as follows:

$$\boldsymbol{Total\ Energy} = KE + PE$$

$$\boldsymbol{Total\ Energy} = 329.84 + 83.22 = 413.06$$

The equation below is used to calculate the level of energy experienced by the worker who is completing the task based on the maximum total energy:

$$\boldsymbol{Level\ of\ Energy} = \frac{Total\ Energy}{Maximum\ Energy\ Possible} \times 100$$

$$\boldsymbol{Level\ of\ Energy} = \frac{413.06}{875} \times 100 = 47\%$$

After calculating the level of energy using the energy model, a project manager or project engineer will have a total energy value and the level of energy relative to the maximum (see Equations 6.9 and 6.10), revealing the level of energy felt by the worker with respect to task performance. The project manager can use the level of energy for evaluating worker performance. As mentioned above, the level of energy can range from 0% to 100%. In the example above, the level of energy is 47%, which means that the level of energy is medium, as seen in Figure 6.2. If the project manager feels that the level of energy is affecting worker performance, adjustments should be made to lower the level of energy. To decrease the level of energy, the project manager should focus on the higher constituent values, such as crowding, interruptions, and pace of the task in the example.

When project managers or supervisors are evaluating the level of energy calculated to determine the potential performance of the worker, a lower level of energy is desired. However, the optimum amount of energy for a task has not yet been determined in the research. Future research could look into the optimum amount of energy for each type of task. After applying the implementation tool on a construction site, the energy felt by the workers can be used to evaluate worker performance.

# 7. CHAPTER 7 – CONCLUSIONS AND RECOMMENDATIONS

## 7.1 INTRODUCTION

This chapter summarizes the steps of the research and discusses the study's conclusions, limitations, and recommendations. Also, this chapter shows how this research contributes to knowledge and practice.

## 7.2 SUMMARY

The primary goal of this research was to develop an implementation tool for evaluating worker performance using the energy concept. The level of energy is a respectable way to evaluate worker performance. Worker performance is reflected in the extent to which workers/crew members work safely and produce quality work.

To achieve the goal of the research, five objectives were established: (1) Identify constituents that impact energy, (2) Identify and verify the relative impact of each constituent on energy using inputs from subject-matter experts, (3) Develop and identify components for each constituent, (4) Develop a metric for each component, (5) Develop a resource that utilizes the energy model to evaluate worker performance on a construction site.

The research methodology was preformed using mixed-methods to achieve these objectives. Firstly, a conceptual model was identified using previous research and a literature review. The conceptual model served as a basis for the intended evaluation method. The conceptual model consisted of three levels (constituents, components, and metrics) to determine the level of energy. Next, a literature review was conducted to identify existing energy constituents and their components, and 14 panelists were selected to identify, verify, and quantify the constituents and components using the Delphi method.

Finally, an implementation tool for evaluating and assessing worker performance using the energy concept was developed.

The survey, which involved 14 experts and four survey rounds, was used to: (1) verify and quantify existing energy constituents, (2) finalize constituents and identify components for each constituent, (3) finalize components for each constituent, (4) confirm the energy quantification and energy model. The results of the survey process are 14 constituents, 53 components, and one metric for each component to evaluate the level of energy. Afterward, the researcher used the results of the study to create an energy model for evaluating worker performance.

## 7.3 LIMITATIONS

This research has been limited by some challenges that restrict its accuracy and ability to simplify the outcomes to apply to a broader population. The identified limitations include the following:

i. Although the research was based on input from a group of experts and the panelists were asked to answer the questions from the workers' perspective to minimize potential discrepancy, the construction workers might have a different perception of constituents and components that should be added or suggested to measure the level of energy. Using a survey method may not give as accurate results as the experimental approach may give: therefore, the result of this study may be biased compared with field workers.

ii. The Delphi mothed took approximately six months to complete all four rounds, and each round of the Delphi method took the panelists approximately 20-25 minutes to complete, which resulted in incomplete information and some panelists not completing all rounds of the Delphi process. It is likely that the panel members did not want to spend much time completing each round of the survey. Due to this limitation, the quality of the result could be affected. To avoid the poor quality of the result, the surveys were designed such that the expert panelists did not have to expend much time and thought to provide their answers. To reduce the amount of time required, the researchers chose to use advanced online survey tools instead of Microsoft Word.

iii. For those incomplete responses from the Delphi panel regarding what potential components can be used to measure each constituent, the research team used available information in the literature to match the information received from the panel. Using on the information available in the literature is a reliable way to ensure that the researcher is unbiased and that the study is objective.

iv. Due to the lack of previous research conducted regarding the energy concept in the construction field, the literature review identified a limited number of constituents and components. Consequently, there might be numerous vital constituents and components that have not been identified in this study. Due to this limitation, the research results might have not guaranteed accurate regarding the energy concept in the construction field.

## 7.4 CONCLUSIONS AND CONTRIBUTIONS

### 7.4.1 CONCLUSIONS

The energy model involves 14 constituents, 53 components, and one metric for each component to measure the level of energy. The 14 constituents were also confirmed by the experts based on the impact on energy. Each constituent has weight which was based on the level of impact on energy using Likert scale from 0 to 7. Also, the panel members agreed that the impact of a constituent could decrease or increase the energy depending on the task scenario. In this study, 10 constituents have an increasing impact on energy whereas 4 constituents have a decreasing impact on energy. The type of constituents was based on the recommendations of previous studies related to safety, quality, psychology, human factors, personnel management, worker performance, or similar field

The constituent value is determined by the components. Once all of the constituents are given a value based on their respective components, the values of all of the constituents are used to reveal the level of energy. For each constituent, three to five components are used to calculate the constituent value. In this research, the number of components were 53 components that found from previous research. A complete list of the components along with their level of impact was provided in Section 5.4. Additionally, for each component, a metric scale is used to calculate the component value. In this study, a metric scale was developed as a linear scale for each component (e.g., 0,1,2,3,4,5).

The evaluation process yields a summed total amount of kinetic energy and potential energy, reflecting the total level of energy. The total energy is determined based on constituents, components, and metrics.

After developing and identifying the constituents, components, and metrics, the energy model was established. The next step was to develop a tool that can be used to implement the model in practice. Each expert panelist was asked to review and confirm the energy model that was developed to calculate the level of "energy" that a worker feels when conducting work on a construction site. The majority of panelists agreed that the overall energy model could be applied to measure the level of energy associated with a task(s) on a construction site.

### 7.4.2 CONTRIBUTIONS

According to Dai et al. (2009), methods for predicting project performance need to be developed. To do as recommended by Dai et al., the impacts of project factors, resources, and site conditions on project performance criteria, such as worker safety, should also be developed (Nnaji and Gambatese 2016). Nnaji (2015) identified energy constituents and developed a new concept of using energy in the construction industry to evaluate worker performance.

The contribution of this research to *knowledge* is the validation and identification of constituents, components, and metrics that can be used for evaluating worker performance using the energy concept. This research verified energy constituents, determined their extent of the impact on the level of energy, and created a tool for calculating the overall level of energy felt by a worker.

Due to the complexity of the construction industry, the Construction Industry Institute (CII 2000) has endorsed that there are factors such as safety, quality, and productivity that need to be measured to determine project performance. CII recommends that factors such as safety, quality, cost, schedule, changes, and productivity should be measured to determine project performance (CII 2000). This research was conducted to develop a means to evaluate performance with respect to these factors. Specifically, the research was conducted to identify and verify the essential energy constituents and components that affect the level of energy and can be used to measure and the expected impact on safety and quality in the construction industry.

In this study, the constituents, components, and metrics were used to create an implementation tool that can be used to measure the impact on safety and quality. Therefore, the contribution of this study to *practice* is the developed model to help project managers or supervisors evaluate worker performance depending on the level of energy.

## 7.5 RECOMMENDATIONS FOR FUTURE RESEARCH

As mentioned in the summary section of Chapter 7, the current research study successfully answered the research questions. This research focused on developing the energy model that can be used to evaluate worker performance based on the level of energy. Below are recommendations for future research:

i. The development of the energy model is expected to be the foundation for future studies in the construction industry as this model is the first of its kind to identify and assess energy constituents, components, and metrics. However, application and implementation of the developed model are needed to ensure that the tool can be easily applied to different types of tasks. Future research is needed to apply and test the energy model on a construction site. A case study would be beneficial as part of the future research. The case study would include applying the implementation tool to different types of tasks to determine a specific energy value depending on the type of task.

ii. This study has identified and verified the relationship between energy and constituents. An additional study should be conducted to find the relationship between constituents and how each constituent impacts the other constituents.

iii. A supporting study after testing the energy model is essential to examine the correlation between the level of energy and key performance indicators, such as safety, work quality, and worker productivity. It is expected that such an additional study would help to justify the importance of the energy model and generate interest in it.

iv. A website or an application to let users easily access the energy model to measure the level of energy for workers is needed to ensure that the model will be used by a large number of construction organizations. The website or application will minimize the time and paperwork required to evaluate the task.

v. Project performance could be measured using various indicators. This research focused on evaluating just two project performance indicators: quality and safety. Future research could look into how energy could be used for other project performance indicators such as productivity, cost, etc.

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# APPENDIX

Appendix A: Survey Questionnaire and IRB Approval

Appendix $A_1$: IRB Approval

**Oregon State University**
**Research Office**

Human Research Protection Program
& Institutional Review Board
B308 Kerr Administration Bldg, Corvallis OR 97331
(541) 737-8008
IRB@oregonstate.edu
http://research.oregonstate.edu/irb

| | | | |
|---|---|---|---|
| Date of Notification | November 12, 2019 | | |
| Notification Type | Approval Notice | | |
| Submission Type | Initial Application | Study Number | IRB-2019-0372 |
| Principal Investigator | John A Gambatese | | |
| Study Team Members | Alotaibi, Abdulaziz M; | | |
| Study Title | Evaluating Worker Performance Using the Energy Concept | | |
| Review Level | FLEX | | |
| Waiver(s) | Documentation of Informed Consent | | |
| Risk Level for Adults | Minimal Risk | | |
| Risk Level for Children | Study does not involve children | | |
| Funding Source | None | Cayuse Number | N/A |

**APPROVAL DATE:** 11/12/2019 **EXPIRATION DATE:** 11/11/2024

A new application will be required in order to extend the study beyond this expiration date.

**Comments**: Waiver of documentation of informed consent under institutional policy.

The above referenced study was approved by the OSU Institutional Review Board (IRB). The IRB has determined that the protocol meets the minimum criteria for approval under the applicable regulations pertaining to human research protections. The Principal Investigator is responsible for ensuring compliance with any additional applicable laws, University or site-specific policies, and sponsor requirements.

Study design and scientific merit have been evaluated to the extent required to determine that the regulatory criteria for approval have been met [45CFR46.111(a)(1)(i), 45CFR46.111(a)(2)].

**Adding any of the following elements will invalidate the FLEX determination and require the submission of a project revision:**

- Increase in risk
- Federal funding or a plan for future federal sponsorship (e.g., proof of concept studies for federal RFPs, pilot studies intended to support a federal grant application, training and program project grants, no-cost extensions)
- Research funded or otherwise regulated by a federal agency that has signed on to the Common Rule, including all agencies within the Department of Health and Human Services
- FDA-regulated research
- NIH-issued or pending Certificate of Confidentiality
- Prisoners or parolees as subjects
- Contractual obligations or restrictions that require the application of the Common Rule or which require annual review by an IRB
- Classified research
- Clinical interventions

Appendix $A_2$: The Delphi Invitation

**The Delphi Invitation**

Dear [insert first name of email recipient],

We are conducting a research study to evaluate worker performance and the level of "energy" that a worker feels in connection with his/her work on a construction site. Given your background and experience related to the construction industry, we would like to invite you to be a part of this research study. Participation involves completing multiple rounds of surveys as part of an expert panel.

Please let me know if you are willing to participate in the study. If you agree to join the expert panel, we will send you the questionnaire for the first round of the survey. We expect that there will be approximately four rounds of the survey, which will be conducted electronically over an approximately 3-4 month period. Each round of the survey is expected to take up to 15 minutes to complete.

Attached is an explanation of the research study. The purpose of this study is to develop a way to assess potential worker performance and impacts based on the level of "energy" that a worker feels when conducting his/her work. Constituents that impact the level of energy experienced, such as task complexity, repetitiveness, distractions, and pace of the work, have been identified in previous research. However, further research is required to verify/validate the constituents, determine their extent of impact on the level of energy, and create a process for calculating the overall level of energy felt by a worker.

Participation in the research study is voluntary. There is no direct benefit for you as a participant or the organization that you belong to. However, the study benefits the industry as a whole by providing a new way to assess worker performance and how that performance ultimately impacts overall project performance criteria such as safety and quality.

Participating in the study has no risks to you as a participant or your organization. All information provided will be kept strictly confidential. Personal and company names are not required or recorded. Names of participants will only be known to the researchers and not to the other panelists, nor shared with the public. Publications of the study results will not include any information about your identity or affiliation.

For more information about this study, please contact the research team: Abdulaziz Alotaibi (Graduate Student) at alotaia8@oregonstate.edu, and Dr. John Gambatese (Professor) by phone at 541-737-8913 or email at john.gambatese@oregonstate.edu.

Thank you,

Abdulaziz Alotaibi

Graduate student researcher

Study Title: Evaluating Worker Performance Using the Energy Concept

Appendix $A_3$: Delphi Survey Questionnaire

**Round 1: Verify and Quantify Existing Energy Constituents**

**Part I: Personal Demographic Information**

1- What is the highest level of education that you have completed or the highest degree that you have received, and in what academic area(s)? Please only list those degrees that relate to the focus of the study (e.g., civil engineering, construction engineering and management, occupational safety and health, quality management, etc.).

☐ BSc (or equivalent degree) Click or tap here to enter text.

☐ MSc (or equivalent degree) Click or tap here to enter text.

☐ PhD (or equivalent degree) Click or tap here to enter text.

☐ Other, please explain: Click or tap here to enter text.

2- What type(s) of organization(s) do you work for? (Please select all that apply.)

☐ University

☐ Research Institute

☐ Architecture, Engineering, or Construction Association

☐ Design Firm

☐ Construction Firm

☐ Design and Construction Firm

☐ Owner organization

☐ Consulting Firm

☐ Other (Please specify): Click or tap here to enter text.

3- Which of the following best describes your current job title?

☐ Faculty Member; please specify rank Click or tap here to enter text.

☐ Independent Researcher; please specify rank Click or tap here to enter text.

☐ Upper Management (President, COE, Vice President, or other)

☐ Project Manager

☐ Project Engineer

☐ Safety Engineer

☐ Foreman

☐ Superintendent

☐ Owner’s Representative

☐ Other (please specify): Click or tap here to enter text.

3- How many years of professional experience do you have working for the following entities? (Please select all that apply.)

☐ University Click or tap here to enter text.

☐ Research Institute Click or tap here to enter text.

☐ Architecture, Engineering, or Construction Association Click or tap here to enter text.

☐ Design Firm Click or tap here to enter text.

☐ Construction Firm Click or tap here to enter text.

☐ Design and Construction Firm Click or tap here to enter text.

☐ Owner organization Click or tap here to enter text.

☐ Consultant Firm Click or tap here to enter text.

☐ Other (please specify): Click or tap here to enter text.

4- What professional affiliations or registrations do you have related to civil/construction engineering, construction safety, quality management, etc.? (Please select all that apply.)

☐ American Society of Civil Engineers (ASCE)

☐ American Society of Safety Professional (ASSP)

☐ Construction Management Association of America (CMAA)

☐ American Institute of Architects (AIA)

☐ American Association of Cost Engineers (AACE)

☐ Other (please specify): Click or tap here to enter text.

5- In what state or U.S. territory do you work?

Click or tap here to enter text.

6- Please list the professional committee(s) in which you are/were a member of or took a leadership role in? Please only list the professional committee(s) that relate to the focus of the study (e.g., safety, quality, psychology, human factors, personnel management, etc.)

Click or tap here to enter text.

7- Approximately how many employees and/or students have you supervised or advised during your working career? (Please specify number and type).

Click or tap here to enter text.

8- How many papers, articles, reports, or other formal publications have you authored or co-authored on topics related to the research topic (e.g., worker performance, safety, quality, health, and psychology)?

☐ Academic journal paper Click or tap here to enter text.

☐ Book or book chapter Click or tap here to enter text.

☐ Conference paper Click or tap here to enter text.

☐ Industry publication (e.g., technical report) Click or tap here to enter text.

☐ Other (please specify): Click or tap here to enter text.

9- How many academic or industry presentation(s) have you given at a conference, workshop, seminar, or other similar venue? Please only list the number of presentations that relate to the topic of the study.

Click or tap here to enter text.

10- Please list the position(s) or role(s) that you have occupied during your working career that are related to the research study topic, along with the number of years within the position/role:

Click or tap here to enter text.

**Part II: Conceptual Energy Constituents**

Before answering the questions below, please read the description of the research topic provided along with the definitions of the terms used.

11- The following constituents have been identified in previous research as those factors that affect the level of "energy" (i.e., combined mental and physical demand) felt by workers as they perform a task:

- Complexity of the task
- Uniqueness of the task
- Predictability of the task
- Repetitiveness of the task
- Availability of needed resources
- Duration of the task
- Time remaining to complete the task
- Crowding
- Coordination
- Value of the task
- Interruptions
- Distractions
- Pace of the task
- Switching between tasks

Based on your experience, please indicate your level of agreement with the following statement: The proposed conceptual energy constituents are appropriate for evaluating the level of" energy" that a worker feels in connection with his/her work on a construction site.

☐ 5: Strongly agree
☐ 4: Agree
☐ 3: Somewhat agree
☐ 2: Disagree
☐ 1: Strongly disagree

Please provide any suggestions, thoughts, comments, etc. regarding the constituents:

Click or tap here to enter text.

12- For each constituent, please indicate the level of impact that the constituent has on the level of "energy" felt by a worker on construction sites as they perform their work. Please use a scale from 0-7 where 0 = No impact and 7 = Extreme impact. Also, indicate if the constituent has an increasing or decreasing impact on energy.

A. **Complexity of the task:** The mental and physical demand related to a work assignment differs from task-to-task. In some cases a task is multifaceted, intricate, and complicated, and may require significant thought and special skills to perform. Tasks that are highly complex can exist on any type and size of project.

| **Constituent** | **Impact on the level of energy?** | | **If Yes, how much impact?** | **Does the impact increase or decrease the energy?** |
|---|---|---|---|---|
| Complexity of the task | Yes ☐ | No ☐ | Choose an item. | Choose an item. |

B. **Uniqueness of the task:** Some tasks required to produce a project differ from regularly-performed work and are unique to the project. Construction employees who lack experience may not be familiar with performing such unique tasks.

| **Constituent** | **Impact on the level of energy?** | | **If Yes, how much impact?** | **Does the impact increase or decrease the energy?** |
|---|---|---|---|---|
| Uniqueness of the task | Yes ☐ | No ☐ | Choose an item. | Choose an item. |

C. **Predictability of the task:** Construction often incorporates uncertainty in the work performed. While processes have been developed to simplify and streamline activities, some tasks associated with an activity may be unpredictable due to a lack of information about the task, a lack of requisite skills by the workers, uncertainty about the jobsite conditions, and other work operations and conditions (e.g., unpredictability of the work tasks due to unknown information).

| **Constituent** | **Impact on the level of energy?** | | **If Yes, how much impact?** | **Does the impact increase or decrease the energy?** |
|---|---|---|---|---|
| Predictability of the task | Yes | No | Choose an item. | Choose an item. |
| | ☐ | ☐ | | |

D. **Repetitiveness of the task:** If a task is required to be executed often by a worker, the worker will find the task to be repetitive and may feel differently about the task compared with other, less repetitive tasks performed. Differences in task performance may be a result of familiarity developed over time (e.g., learning curve).

| **Constituent** | **Impact on the level of energy?** | | **If Yes, how much impact?** | **Does the impact increase or decrease the energy?** |
|---|---|---|---|---|
| Repetitiveness of the task | Yes | No | Choose an item. | Choose an item. |
| | ☐ | ☐ | | |

E. **Availability of needed resources:** Resources (e.g., materials, equipment, labor, etc.) are a significant part of all construction projects, and resource availability is a critical factor for the work to be accomplished.

| **Constituent** | **Impact on the level of energy?** | | **If Yes, how much impact?** | **Does the impact increase or decrease the energy?** |
|---|---|---|---|---|
| Availability of needed resources | Yes | No | Choose an item. | Choose an item. |
| | ☐ | ☐ | | |

F. **Duration of the task:** Each task on a project is typically assigned a duration. This duration helps management verify the progress of a project. In certain cases, the prescribed duration of a task could impact the worker's performance (e.g., if the required task duration is reduced significantly to accommodate a change in project schedule).

| **Constituent** | **Impact on the level of energy?** | | **If Yes, how much impact?** | **Does the impact increase or decrease the energy?** |
|---|---|---|---|---|
| Duration of the task | Yes<br>☐ | No<br>☐ | Choose an item. | Choose an item. |

G. **Time remaining to complete the task:** In most cases, workers have several tasks lined up to work on for a project. Each task should be completed within a specific duration. However, as workers approach the stipulated completion time, they could be under additional pressure due to the amount of work still to be completed within the time remaining to complete that task.

| **Constituent** | **Impact on the level of energy?** | | **If Yes, how much impact?** | **Does the impact increase or decrease the energy?** |
|---|---|---|---|---|
| Time remaining to complete the task | Yes<br>☐ | No<br>☐ | Choose an item. | Choose an item. |

H. **Crowding:** Performing work on a construction site requires space to bring in materials and equipment and perform the required work operations. A construction site may become crowded if many multiple crews and/or different trades are required to work in the same area on the project within a specified timeframe. The size and location of the work area available may also increase or decrease the extent of crowding experienced on a project.

| **Constituent** | **Impact on the level of energy?** | | **If Yes, how much impact?** | **Does the impact increase or decrease the energy?** |
|---|---|---|---|---|
| Crowding | Yes<br>☐ | No<br>☐ | Choose an item. | Choose an item. |

I. **Coordination:** Coordination of the work plays a vital role in executing a construction project since it helps to reduce space and operational conflicts, and enhances teamwork and collaboration. At a task level, coordination might make executing a task more efficient.

| **Constituent** | **Impact on the level of energy?** | | **If Yes, how much impact?** | **Does the impact increase or decrease the energy?** |
|---|---|---|---|---|
| Coordination | Yes<br>☐ | No<br>☐ | Choose an item. | Choose an item. |

J. **Value of the task:** All tasks on construction projects are valuable since they consume resources and contribute to completion of the project. In addition to the cost and resources used/consumed, the value of a task can vary depending on its complexity, criticality (relative to the critical path), and the type and availability of labor and equipment required to complete the task. Hence, the value of a task could impact a worker's performance on a project.

| Constituent | Impact on the level of energy? | | If Yes, how much impact? | Does the impact increase or decrease the energy? |
|---|---|---|---|---|
| Value of the task | Yes | No | Choose an item. | Choose an item. |
| | ☐ | ☐ | | |

K. **Interruptions:** While a worker is working on an activity, he/she may need to stop in order to talk with a fellow employee, attend to problems related to the project, replenish material stockpiles, assist an inexperienced crew member, attend to personal business, etc. The interruptions could be internal or external to the project.

| Constituent | Impact on the level of energy? | | If Yes, how much impact? | Does the impact increase or decrease the energy? |
|---|---|---|---|---|
| Interruptions | Yes | No | Choose an item. | Choose an item. |
| | ☐ | ☐ | | |

L. **Distractions:** While conducting their work tasks, workers may be mentally distracted by the surrounding work conditions, personal interactions with others on or off the jobsite, or other issues of concern. A distraction can be anything that inhibits workers from paying attention to the task or duty (e.g., adverse weather condition).

| **Constituent** | **Impact on the level of energy?** | | **If Yes, how much impact?** | **Does the impact increase or decrease the energy?** |
|---|---|---|---|---|
| Distractions | Yes | No | Choose an item. | Choose an item. |
| | ☐ | ☐ | | |

M. **Pace of the task:** This is an important factor that drives work execution. The pace of the task is considered as the time taken to perform a specified amount of task. A faster pace means more work is being accomplished in a given period of time.

| **Constituent** | **Impact on the level of energy?** | | **If Yes, how much impact?** | **Does the impact increase or decrease the energy?** |
|---|---|---|---|---|
| Pace of the task | Yes | No | Choose an item. | Choose an item. |
| | ☐ | ☐ | | |

N. **Switching between tasks**: Some workers may be assigned multiple tasks to perform in a given shift. In some cases the timing of the tasks may overlap. Switching between tasks occurs when a worker attempts to go from one task to another to accomplish both tasks during the same time period. Switching may also occur when a worker is given new tasks very frequently during the work shift.

| **Constituent** | **Impact on the level of energy?** | | **If Yes, how much impact?** | **Does the impact increase or decrease the energy?** |
|---|---|---|---|---|
| Switching between tasks | Yes ☐ | No ☐ | Choose an item. | Choose an item. |

13- Please provide any comments or suggestions related to the energy constituents and their impact on work performance. Feel free to also suggest additions, deletions, or modifications to any of the constituent descriptions.
Click or tap here to enter text.

Thank you for completing Round 1 of the survey. We very much appreciate your time devoted to the study.
**Please send your completed survey questionnaire file to the researchers via email using the email addresses below.**
If you have any questions and/or concerns related to the research study, please do not hesitate to reach us at the following email addresses:

Abdulaziz Alotaibi
alotaia8@oregonstate.edu

John Gambatese
john.gambatese@oregonstate.edu

## Round 2: Finalize Constituents and Identify Components for Each Constituent

### Part I: Energy Constituents

This part of the Round 2 survey shows the results of the Round 1 survey and allows panel members to revise their Round 1 responses, if desired, based on the aggregated group response. The objective of this part is to reach consensus regarding the extent to which each constituent influences worker performance.

The Round 1 questions asked panelists to rate the level of impact that each constituent has on the level of “energy” felt by workers when performing their work. Your Round 1 responses and the group aggregated responses are shown in the table below. Please fill in the remaining information in the table for each constituent as applicable. Please use a rating scale from 0 to 7 where: 0 = No impact, 1 = Low impact, and 7 = Extreme impact. If your final response is two or more units away from the aggregated group response, please explain and justify your final response.

| Constituents | Your Response in Round 1 | | | Group Aggregated Response in Round 1 | | | Retain your response? (Yes/No) | If No, provide updated response | If final response is two or more units away from group response, please explain why? |
|---|---|---|---|---|---|---|---|---|---|
| | Impact on the level of energy? (Yes/No) | Scale of Impact | Does the impact increase or decrease the energy? | Impact on the level of energy? (Yes /No) | Scale of Impact (median) | Does the impact increase or decrease the energy? | | | |
| Complexity of the task | | | | | | | | | |
| Uniqueness of the task | | | | | | | | | |
| Predictability of the task | | | | | | | | | |
| Repetitiveness of the task | | | | | | | | | |
| Availability of needed resources | | | | | | | | | |
| Duration of the task | | | | | | | | | |
| Time remaining to complete the task | | | | | | | | | |
| Crowding | | | | | | | | | |
| Coordination | | | | | | | | | |
| Value of the task | | | | | | | | | |
| Interruptions | | | | | | | | | |
| Distractions | | | | | | | | | |
| Pace of work | | | | | | | | | |
| Switching between tasks | | | | | | | | | |

## Part II: Components for Each Constituent

In this part, you will be asked to suggest and categorize potential components that can be used to measure each constituent (complexity, uniqueness, predictability of task, repetitiveness of the task, availability of needed resources, duration of the task, time remaining to complete the task, crowding, coordination, value of the task, interruptions, distractions, pace, and switching between activities).

1- An initial list of components has been developed for each constituent as shown in the tables below. For each component, please indicate whether you think the component impacts the constituent and, if so, the extent of impact. Use a rating scale from 0 to 7 where: 0 = No impact, 1 = Low impact, and 7 = Extreme impact. Please also list any additional components that you think impact the constituent as well as their level of impact.

**A. Complexity of the task:** The mental and physical demand related to a work assignment differs from task-to-task. In some cases a task is multifaceted, intricate, and complicated, and may require significant thought and special skills to perform. Tasks that are highly complex can exist on any type and size of project.

| Constituent | Components | Impact on the complexity of the task? (Yes/No) | If Yes, how much impact? | If No, should it be removed from the list? | Does the impact increase or decrease the complexity of the task? |
|---|---|---|---|---|---|
| Complexity of the task | Task size | Choose an item. | Choose an item. | Choose an item. | Choose an item. |
| | Task budget | Choose an item. | Choose an item. | Choose an item. | Choose an item. |
| | Pre-planning | Choose an item. | Choose an item. | Choose an item. | Choose an item. |
| | Task execution | Choose an item. | Choose an item. | Choose an item. | Choose an item. |
| | Number of steps | Choose an item. | Choose an item. | Choose an item. | Choose an item. |
| | Level of physical strain/exertion | Choose an item. | Choose an item. | Choose an item. | Choose an item. |
| | Other Click or tap here to enter text. | Choose an item. | Choose an item. | Choose an item. | Choose an item. |
| | Other Click or tap here to enter text. | Choose an item. | Choose an item. | Choose an item. | Choose an item. |

**B. Uniqueness of the task:** Some tasks required to produce a project differ from regularly-performed work and are unique to the project. Construction employees who lack of experience may not be familiar with performing such unique tasks.

| Constituent | Components | Impact on the uniqueness of the task? (Yes/No) | If Yes, how much impact? | If No, should it be removed from the list? | Does the impact increase or decrease the uniqueness of the task? |
|---|---|---|---|---|---|
| Uniqueness of the task | Special skills/experience needed to perform the task(s) | Choose an item. | Choose an item. | Choose an item. | Choose an item. |
| | Task new to worker | Choose an item. | Choose an item. | Choose an item. | Choose an item. |
| | Task new to industry | Choose an item. | Choose an item. | Choose an item. | Choose an item. |
| | Task new to the project/company | Choose an item. | Choose an item. | Choose an item. | Choose an item. |
| | Other Click or tap here to enter text. | Choose an item. | Choose an item. | Choose an item. | Choose an item. |
| | Other Click or tap here to enter text. | Choose an item. | Choose an item. | Choose an item. | Choose an item. |

C. **Predictability of the task:** Construction often incorporates uncertainty in the work performed. While processes have been developed to simplify and streamline activities, some tasks associated with an activity may be unpredictable due to a lack of information about the task, a lack of requisite skills by the workers, uncertainty about the jobsite conditions, and other work operations and conditions (e.g., unpredictability of the work tasks due to unknown information).

| **Constituent** | **Components** | **Impact on the predictability of the task? (Yes/No)** | **If Yes, how much impact?** | **If No, should it be removed from the list?** | **Does the impact increase or decrease the predictability of the task?** |
|---|---|---|---|---|---|
| Predictability of the task | Uncertainty about task scope and performance at start | Choose an item. | Choose an item. | Choose an item. | Choose an item. |
| | Uncertainty about task scope and performance during execution of the task | Choose an item. | Choose an item. | Choose an item. | Choose an item. |
| | Task duration is not predictable | Choose an item. | Choose an item. | Choose an item. | Choose an item. |
| | Other Click or tap here to enter text. | Choose an item. | Choose an item. | Choose an item. | Choose an item. |
| | Other Click or tap here to enter text. | Choose an item. | Choose an item. | Choose an item. | Choose an item. |

**D. Repetitiveness of the task:** Construction often incorporates uncertainty in the work performed. While processes have been developed to simplify and streamline activities, some tasks associated with an activity may be unpredictable due to a lack of information about the task, a lack of requisite skills by the workers, uncertainty about the jobsite conditions, and other work operations and conditions (e.g., unpredictability of the work tasks due to unknown information).

| **Constituent** | **Components** | **Impact on the repetitiveness of the task? (Yes/No)** | **If Yes, how much impact?** | **If No, should it be removed from the list?** | **Does the impact increase or decrease the repetitiveness of the task?** |
|---|---|---|---|---|---|
| Repetitiveness of the task | Task is performed more than once | Choose an item. | Choose an item. | Choose an item. | Choose an item. |
| | Task duration is long | Choose an item. | Choose an item. | Choose an item. | Choose an item. |
| | Task is continuous | Choose an item. | Choose an item. | Choose an item. | Choose an item. |
| | Other Click or tap here to enter text. | Choose an item. | Choose an item. | Choose an item. | Choose an item. |
| | Other Click or tap here to enter text. | Choose an item. | Choose an item. | Choose an item. | Choose an item. |

**E. Availability of needed resources:** Resources (e.g., materials, equipment, labor, etc.) are a significant part of all construction projects, and resource availability is a critical factor for the work to be accomplished.

| **Constituent** | **Components** | **Impact on the availability of needed resources? (Yes/No)** | **If Yes, how much impact?** | **If No, should it be removed from the list?** | **Does the impact increase or decrease the availability of needed resources?** |
|---|---|---|---|---|---|
| Availability of needed resources | Presence of materials and tools | Choose an item. | Choose an item. | Choose an item. | Choose an item. |
| | Presence of appropriate equipment storage | Choose an item. | Choose an item. | Choose an item. | Choose an item. |
| | Familiarity with the materials and equipment | Choose an item. | Choose an item. | Choose an item. | Choose an item. |
| | Quality of material, tools, and equipment | Choose an item. | Choose an item. | Choose an item. | Choose an item. |
| | Presence of labor force/crew members who can perform the task | Choose an item. | Choose an item. | Choose an item. | Choose an item. |
| | Presence of capable supervisor | Choose an item. | Choose an item. | Choose an item. | Choose an item. |
| | Availability of PPE | Choose an item. | Choose an item. | Choose an item. | |
| | Other Click or tap here to enter text. | Choose an item. | Choose an item. | Choose an item. | Choose an item. |
| | Other Click or tap here to enter text. | Choose an item. | Choose an item. | Choose an item. | Choose an item. |

**F. Duration of the task:** Each task on a project is typically assigned a duration. This duration helps management verify the progress of a project. In certain cases, the prescribed duration of a task could impact the worker's performance (e.g., if the required task duration is reduced significantly to accommodate a change in project schedule).

| **Constituent** | **Components** | **Impact on the duration of the task? (Yes/No)** | **If Yes, how much impact?** | **If No, should it be removed from the list?** | **Does the impact increase or decrease the duration of the task?** |
|---|---|---|---|---|---|
| Duration of the task | Time required to complete the task | Choose an item. | Choose an item. | Choose an item. | Choose an item. |
| | Time available to complete the task | Choose an item. | Choose an item. | Choose an item. | Choose an item. |
| | Availability of a buffer | Choose an item. | Choose an item. | Choose an item. | Choose an item. |
| | Other Click or tap here to enter text. | Choose an item. | Choose an item. | Choose an item. | Choose an item. |
| | Other Click or tap here to enter text. | Choose an item. | Choose an item. | Choose an item. | Choose an item. |

G. **Time remaining to complete the task:** In most cases, workers have several tasks lined up to work on for a project. Each task should be completed within a specific duration. However, as workers approach the stipulated completion time, they could be under additional pressure due to the amount of work still to be completed within the time remaining to complete that task.

| **Constituent** | **Components** | **Impact on the time remaining to complete the task? (Yes/No)** | **If Yes, how much impact?** | **If No, should it be removed from the list?** | **Does the impact increase or decrease the time remaining to complete the task?** |
|---|---|---|---|---|---|
| Time remaining to complete the task | Time available to finish the remaining parts of the task | Choose an item. | Choose an item. | Choose an item. | Choose an item. |
| | Need for overtime work to complete task | Choose an item. | Choose an item. | Choose an item. | Choose an item. |
| | Other Click or tap here to enter text. | Choose an item. | Choose an item. | Choose an item. | Choose an item. |
| | Other Click or tap here to enter text. | Choose an item. | Choose an item. | Choose an item. | Choose an item. |

**H. Crowding:** Performing work on a construction site requires space to bring in materials and equipment and perform the required work operations. A construction site may become crowded if many multiple crews and/or different trades are required to work in the same area on the project within a specified timeframe. The size and location of the work area available may also increase or decrease the extent of crowding experienced on a project.

| Constituent | Components | Impact on crowding? (Yes/No) | If Yes, how much impact? | If No, should it be removed from the list? | Does the impact increase or decrease crowding? |
|---|---|---|---|---|---|
| Crowding | Many different subcontractors or crews/trades on site at the same time | Choose an item. | Choose an item. | Choose an item. | Choose an item. |
| | Many different tasks/activities in the same work area | Choose an item. | Choose an item. | Choose an item. | Choose an item. |
| | Size of work area relative to number of workers and size of crew present | Choose an item. | Choose an item. | Choose an item. | Choose an item. |
| | Extent of materials and equipment present in the work area | Choose an item. | Choose an item. | Choose an item. | Choose an item. |
| | Presence of materials and equipment in the work area | Choose an item. | Choose an item. | Choose an item. | Choose an item. |
| | Other Click or tap here to enter text. | Choose an item. | Choose an item. | Choose an item. | Choose an item. |
| | Other Click or tap here to enter text. | Choose an item. | Choose an item. | Choose an item. | Choose an item. |

I. **Coordination:** Coordination of the work plays a vital role in executing a construction project since it helps to reduce space and operational conflicts, and enhances teamwork and collaboration. At a task level, coordination might make executing a task more efficient.

| **Constituent** | **Components** | **Impact on coordination? (Yes/No)** | **If Yes, how much impact?** | **If No, should it be removed from the list?** | **Does the impact increase or decrease coordination?** |
|---|---|---|---|---|---|
| Coordination | Amount of pre-planning | Choose an item. | Choose an item. | Choose an item. | Choose an item. |
| | Amount of job site management | Choose an item. | Choose an item. | Choose an item. | Choose an item. |
| | Quality of job site management | Choose an item. | Choose an item. | Choose an item. | Choose an item. |
| | Other Click or tap here to enter text. | Choose an item. | Choose an item. | Choose an item. | Choose an item. |
| | Other Click or tap here to enter text. | Choose an item. | Choose an item. | Choose an item. | Choose an item. |

**J. Value of the task:** All tasks on construction projects are valuable since they consume resources and contribute to completion of the project. In addition to the cost and resources used/consumed, the value of a task can vary depending on its complexity, criticality (relative to the critical path), and the type and availability of labor and equipment required to complete the task. Hence, the value of a task could impact a worker's performance on a project.

| **Constituent** | **Components** | **Impact on the value of the task? (Yes/No)** | **If Yes, how much impact?** | **If No, should it be removed from the list?** | **Does the impact increase or decrease the value of the task?** |
|---|---|---|---|---|---|
| Value of the task | Value of task outcome to worker/crew | Choose an item. | Choose an item. | Choose an item. | Choose an item. |
| | Value of materials being used and put in place | Choose an item. | Choose an item. | Choose an item. | Choose an item. |
| | Value of equipment used for the operation | Choose an item. | Choose an item. | Choose an item. | Choose an item. |
| | Significance of task to the timely completion of the project (i.e., on the critical path or not) | Choose an item. | Choose an item. | Choose an item. | Choose an item. |
| | Significance of the task to successful completion of the project | Choose an item. | Choose an item. | Choose an item. | Choose an item. |
| | Other Click or tap here to enter text. | Choose an item. | Choose an item. | Choose an item. | Choose an item. |
| | Other Click or tap here to enter text. | Choose an item. | Choose an item. | Choose an item. | Choose an item. |

**K. Interruptions:** While a worker is working on an activity, he/she may need to stop in order to talk with a fellow employee, attend to problems related to the project, replenish material stockpiles, assist an inexperienced crew member, attend to personal business, etc. The interruptions could be internal or external to the project.

| Constituent | Components | Impact on interruptions? (Yes/No) | If Yes, how much impact? | If No, should it be removed from the list? | Does the impact increase or decrease interruptions? |
|---|---|---|---|---|---|
| Interruptions | Need to help inexperience crew member | Choose an item. | Choose an item. | Choose an item. | Choose an item. |
| | Construction drawings availability | Choose an item. | Choose an item. | Choose an item. | Choose an item. |
| | Extent and types of interruptions | Choose an item. | Choose an item. | Choose an item. | Choose an item. |
| | Number of overlapping work activities for crew members | Choose an item. | Choose an item. | Choose an item. | Choose an item. |
| | Quality of detailed design drawings | Choose an item. | Choose an item. | Choose an item. | Choose an item. |
| | Frequent change orders | | | Choose an item. | |
| | Other Click or tap here to enter text. | Choose an item. | Choose an item. | Choose an item. | Choose an item. |
| | Other Click or tap here to enter text. | Choose an item. | Choose an item. | Choose an item. | Choose an item. |

**L. Distractions:** While conducting their work tasks, workers may be mentally distracted by the surrounding work conditions, personal interactions with others on or off the jobsite, or other issues of concern. A distraction can be anything that inhibits workers from paying attention to the task or duty (e.g., adverse weather condition).

| **Constituent** | **Components** | **Impact on distractions? (Yes/No)** | **If Yes, how much impact?** | **If No, should it be removed from the list?** | **Does the impact increase or decrease distractions?** |
|---|---|---|---|---|---|
| Distractions | Management control | Choose an item. | Choose an item. | Choose an item. | Choose an item. |
| | Experience of supervisor | Choose an item. | Choose an item. | Choose an item. | Choose an item. |
| | Deserved positive feedback (compliments) | Choose an item. | Choose an item. | Choose an item. | Choose an item. |
| | Noise | Choose an item. | Choose an item. | Choose an item. | Choose an item. |
| | Night shifts | Choose an item. | Choose an item. | Choose an item. | Choose an item. |
| | More than one language spoken on construction site | Choose an item. | Choose an item. | Choose an item. | Choose an item. |
| | Project located in urban area (increased vehicle and pedestrian traffic) | Choose an item. | Choose an item. | Choose an item. | Choose an item. |
| | Weather conditions | Choose an item. | Choose an item. | Choose an item. | Choose an item. |
| | Other Click or tap here to enter text. | Choose an item. | Choose an item. | Choose an item. | Choose an item. |
| | Other Click or tap here to enter text. | Choose an item. | Choose an item. | Choose an item. | Choose an item. |

**M. Pace of work:** Productivity is an important factor that drives work execution. The pace of the work is considered as the time taken to perform a specified amount of work. A faster pace of work means more work is being accomplished in a given period of time.

| **Constituent** | **Components** | **Impact on the pace of the work? (Yes/No)** | **If Yes, how much impact?** | **If No, should it be removed from the list?** | **Does the impact increase or decrease the pace of the work?** |
|---|---|---|---|---|---|
| Pace of work | Production rate (e.g., ft/hr, cy/hr, etc.) | Choose an item. | Choose an item. | Choose an item. | Choose an item. |
| | Rework frequency | Choose an item. | Choose an item. | Choose an item. | Choose an item. |
| | Other Click or tap here to enter text. | Choose an item. | Choose an item. | Choose an item. | Choose an item. |
| | Other Click or tap here to enter text. | Choose an item. | Choose an item. | Choose an item. | Choose an item. |

**N. Switching between tasks:** Some workers may be assigned multiple tasks to perform in a given shift. In some cases the timing of the tasks may overlap. Switching between tasks occurs when a worker attempts to go from one task to another to accomplish both tasks during the same time period. Switching may also occur when a worker is given new tasks very frequently during the work shift.

| **Constituent** | **Components** | **Impact on switching between tasks? (Yes/No)** | **If Yes, how much impact?** | **If No, should it be removed from the list?** | **Does the impact increase or decrease switching between tasks?** |
|---|---|---|---|---|---|
| Switching between tasks | Multi-tasking | Choose an item. | Choose an item. | Choose an item. | Choose an item. |
| | Rate in which new tasks are given | Choose an item. | Choose an item. | Choose an item. | Choose an item. |
| | Frequency of substituting for crew member (due to absence, for instance) | | | Choose an item. | |
| | Other Click or tap here to enter text. | Choose an item. | Choose an item. | Choose an item. | Choose an item. |
| | Other Click or tap here to enter text. | Choose an item. | Choose an item. | | Choose an item. |

2- Please provide any comments or suggestions related to the components and their impact on each constituent. Feel free to also suggest additions, deletions, or modifications to any of the components.

Click or tap here to enter text.

Thank you for completing Round 2 of the survey. We very much appreciate your time devoted to the study.

**Please send your completed survey questionnaire file to the researchers via email using the email addresses below.**

If you have any questions and/or concerns related to the research study, please do not hesitate to reach us at the following email addresses:

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## Round 3: Finalize Components for each Constituent

### Components of Energy Constituents

This part of the Round 3 survey shows the results of the Round 2 survey and allows panel members to revise their Round 2 responses, if desired, based on the aggregated group response. The objective of this part is to reach consensus regarding the extent to which each component influences the energy constituents. Round 3 also gives an opportunity for all expert panelists to consider and evaluate the additional components suggested by some panelists during Round 2.

The Round 2 questions asked panelists to identify and confirm components for each energy constituent, and to rate the level of impact that each component has on the constituents. Your Round 2 responses and the group aggregated responses are shown in the tables below. Please fill in the remaining information in the tables for each component as applicable. Please use a rating scale from 0 to 7 where: 0 = No impact, 1 = Low impact, and 7 = Extreme impact. If your final response is two or more units away from the aggregated group response, please explain and justify your final response.

For the additional components suggested by panelists in Round 2, please indicate whether you think the component impacts the constituent and, if so, the extent of the impact. Use a rating scale from 0 to 7 where: 0 = No impact, 1 = Low impact, and 7 = Extreme impact.

**A. Complexity of the task:** The mental and physical demand related to a work assignment differs from task-to-task. In some cases a task is multifaceted, intricate, and complicated, and may require significant thought and special skills to perform. Tasks that are highly complex can exist on any type and size of project.

| **Components** | **Your Response in Round 2** | | | **Group Aggregated Response in Round 2** | | | **Retain your response? (Yes/No)** | **If No, provide updated response** | **If final response is two or more units away from group response, please explain why** |
|---|---|---|---|---|---|---|---|---|---|
| | Impact on the complexity of the task? (Yes/No) | Magnitude of Impact | Does the impact increase or decrease the complexity of the task? | Impact on the complexity of the task? (Yes /No) | Magnitude of Impact (median) | Does the impact increase or decrease the complexity of the task? | | | |
| Task size | Choose an item. | Choose an item. | Choose an item. | | | | Choose an item. | Click or tap here to enter text. | Click or tap here to enter text. |
| Task budget | Choose an item. | Choose an item. | Choose an item. | | | | Choose an item. | Click or tap here to enter text. | Click or tap here to enter text. |
| Pre-planning | Choose an item. | Choose an item. | Choose an item. | | | | Choose an item. | Click or tap here to enter text. | Click or tap here to enter text. |
| Task execution | Choose an item. | Choose an item. | Choose an item. | | | | Choose an item. | Click or tap here to enter text. | Click or tap here to enter text. |
| Number of steps | Choose an item. | Choose an item. | Choose an item. | | | | Choose an item. | Click or tap here to enter text. | Click or tap here to enter text. |
| Level of physical strain/exertion | Choose an item. | Choose an item. | Choose an item. | | | | Choose an item. | Click or tap here to enter text. | Click or tap here to enter text. |

***Additional components suggested by panel members:***

| **Constituent** | **Components** | **Impact on the complexity of the task? (Yes/No)** | **If Yes, how much impact?** | **If No, should it be removed from the list?** | **Does the impact increase or decrease the complexity of the task?** |
|---|---|---|---|---|---|
| Complexity of the task | Limited accessibility | Choose an item. | Choose an item. | Choose an item. | Choose an item. |

**B. Uniqueness of the task:** Some tasks required to produce a project differ from regularly-performed work and are unique to the project. Construction employees who lack of experience may not be familiar with performing such unique tasks.

| **Components** | **Your Response in Round 2** | | | **Group Aggregated Response in Round 2** | | | **Retain your response? (Yes/No)** | **If No, provide updated response** | **If final response is two or more units away from group response, please explain why** |
|---|---|---|---|---|---|---|---|---|---|
| | Impact on the uniqueness of the task? (Yes/No) | Magnitude of Impact | Does the impact increase or decrease the uniqueness of the task? | Impact on the uniqueness of the task? (Yes /No) | Magnitude of Impact (median) | Does the impact increase or decrease the uniqueness of the task? | | | |
| Special skills/experience needed to perform the task(s) | Choose an item. | Choose an item. | Choose an item. | | | | Choose an item. | Click or tap here to enter text. | Click or tap here to enter text. |
| Task new to worker | Choose an item. | Choose an item. | Choose an item. | | | | Choose an item. | Click or tap here to enter text. | Click or tap here to enter text. |
| Task new to industry | Choose an item. | Choose an item. | Choose an item. | | | | Choose an item. | Click or tap here to enter text. | Click or tap here to enter text. |
| Task new to the project/company | Choose an item. | Choose an item. | Choose an item. | | | | Choose an item. | Click or tap here to enter text. | Click or tap here to enter text. |

***<u>Additional components suggested by panel members:</u>***

| **Constituent** | **Components** | **Impact on the uniqueness of the task? (Yes/No)** | | **If Yes, how much impact?** | **If No, should it be removed from the list?** | **Does the impact increase or decrease the uniqueness of the task?** |
|---|---|---|---|---|---|---|
| Uniqueness of the task | Proper training to new/unique task | Choose an item. | | Choose an item. | Choose an item. | Choose an item. |
| | Familiarization with tools for unique task | Choose an item. | | Choose an item. | Choose an item. | Choose an item. |
| | Use of proprietary products | Choose an item. | | Choose an item. | Choose an item. | Choose an item. |
| | Job specifications | Choose an item. | | Choose an item. | Choose an item. | Choose an item. |

**C. Predictability of the task:** Construction often incorporates uncertainty in the work performed. While processes have been developed to simplify and streamline activities, some tasks associated with an activity may be unpredictable due to a lack of information about the task, a lack of requisite skills by the workers, uncertainty about the jobsite conditions, and other work operations and conditions (e.g., unpredictability of the work tasks due to unknown information).

| **Components** | **Your Response in Round 2** | | | **Group Aggregated Response in Round 2** | | | **Retain your response? (Yes/No)** | **If No, provide updated response** | **If final response is two or more units away from group response, please explain why** |
|---|---|---|---|---|---|---|---|---|---|
| | Impact on the predictability of the task? (Yes/No) | Magnitude of Impact | Does the impact increase or decrease the predictability of the task? | Impact on the predictability of the task? (Yes /No) | Magnitude of Impact (median) | Does the impact increase or decrease the predictability of the task? | | | |
| Uncertainty about task scope and performance at start | Choose an item. | Choose an item. | Choose an item. | | | | Choose an item. | Click or tap here to enter text. | Click or tap here to enter text. |
| Uncertainty about task scope and performance during execution of the task | Choose an item. | Choose an item. | Choose an item. | | | | Choose an item. | Click or tap here to enter text. | Click or tap here to enter text. |
| Task duration is not predictable | Choose an item. | Choose an item. | Choose an item. | | | | Choose an item. | Click or tap here to enter text. | Click or tap here to enter text. |

**D. Repetitiveness of the task:** Construction often incorporates uncertainty in the work performed. While processes have been developed to simplify and streamline activities, some tasks associated with an activity may be unpredictable due to a lack of information about the task, a lack of requisite skills by the workers, uncertainty about the jobsite conditions, and other work operations and conditions (e.g., unpredictability of the work tasks due to unknown information).

| **Components** | **Your Response in Round 2** | | | **Group Aggregated response in Round 2** | | | **Retain your response? (Yes/No)** | **If No, provide updated response** | **If final response is two or more units away from group response, please explain why** |
|---|---|---|---|---|---|---|---|---|---|
| | Impact on the repetitiveness of the task? (Yes/No) | Magnitude of Impact | Does the impact increase or decrease the repetitiveness of the task? | Impact on the predictability of the task? (Yes /No) | Magnitude of Impact (median) | Does the impact increase or decrease the repetitiveness of the task? | | | |
| Task is performed more than once | Choose an item. | Choose an item. | Choose an item. | | | | Choose an item. | Click or tap here to enter text. | Click or tap here to enter text. |
| Task duration is long | Choose an item. | Choose an item. | Choose an item. | | | | Choose an item. | Click or tap here to enter text. | Click or tap here to enter text. |
| Task is continuous | Choose an item. | Choose an item. | Choose an item. | | | | Choose an item. | Click or tap here to enter text. | Click or tap here to enter text. |

**E. Availability of needed resources:** Resources (e.g., materials, equipment, labor, etc.) are a significant part of all construction projects, and resource availability is a critical factor for the work to be accomplished.

| **Components** | **Your Response in Round 2** | | | **Group Aggregated Response in Round 2** | | | **Retain your response? (Yes/No)** | **If No, provide updated response** | **If final response is two or more units away from group response, please explain why** |
|---|---|---|---|---|---|---|---|---|---|
| | Impact on the availability of needed resources? (Yes/No) | Magnitude of Impact | Does the impact increase or decrease the availability of needed resources? | Impact on the availability of needed resources? (Yes /No) | Magnitude of Impact (median) | Does the impact increase or decrease the availability of needed resources? | | | |
| Presence of materials and tools | Choose an item. | Choose an item. | Choose an item. | | | | Choose an item. | Click or tap here to enter text. | Click or tap here to enter text. |
| Presence of appropriate equipment storage | Choose an item. | Choose an item. | Choose an item. | | | | Choose an item. | Click or tap here to enter text. | Click or tap here to enter text. |
| Familiarity with the materials and equipment | Choose an item. | Choose an item. | Choose an item. | | | | Choose an item. | Click or tap here to enter text. | Click or tap here to enter text. |
| Quality of material, tools, and equipment | Choose an item. | Choose an item. | Choose an item. | | | | Choose an item. | Click or tap here to enter text. | Click or tap here to enter text. |
| Presence of labor force/crew members who can perform the task | Choose an item. | Choose an item. | Choose an item. | | | | Choose an item. | Click or tap here to enter text. | Click or tap here to enter text. |
| Presence of capable supervisor | Choose an item. | Choose an item. | Choose an item. | | | | Choose an item. | Click or tap here to enter text. | Click or tap here to enter text. |
| Availability of PPE | Choose an item. | Choose an item. | Choose an item. | | | | Choose an item. | Click or tap here to enter text. | Click or tap here to enter text. |

**F. Duration of the task:** Each task on a project is typically assigned a duration. This duration helps management verify the progress of a project. In certain cases, the prescribed duration of a task could impact the worker's performance (e.g., if the required task duration is reduced significantly to accommodate a change in project schedule).

| **Components** | **Your Response in Round 2** | | | **Group Aggregated Response in Round 2** | | | **Retain your response? (Yes/No)** | **If No, provide updated response** | **If final response is two or more units away from group response, please explain why** |
|---|---|---|---|---|---|---|---|---|---|
| | Impact on the duration of the task? (Yes/No) | Magnitude of Impact | Does the impact increase or decrease the duration of the task? | Impact on the repetitiveness of the task? (Yes /No) | Magnitude of Impact (median) | Does the impact increase or decrease the duration of the task? | | | |
| Time required to complete the task | Choose an item. | Choose an item. | Choose an item. | | | | Choose an item. | Click or tap here to enter text. | Click or tap here to enter text. |
| Time available to complete the task | Choose an item. | Choose an item. | Choose an item. | | | | Choose an item. | Click or tap here to enter text. | Click or tap here to enter text. |
| Availability of a buffer | Choose an item. | Choose an item. | Choose an item. | | | | Choose an item. | Click or tap here to enter text. | Click or tap here to enter text. |

***Additional components suggested by panel members:***

| **Constituent** | **Components** | **Impact on the duration of the task? (Yes/No)** | **If Yes, how much impact?** | **If No, should it be removed from the list?** | **Does the impact increase or decrease the duration of the task?** |
|---|---|---|---|---|---|
| Duration of the task | Knowledge of the schedule | Choose an item. | Choose an item. | Choose an item. | Choose an item. |

**G. Time remaining to complete the task:** In most cases, workers have several tasks lined up to work on for a project. Each task should be completed within a specific duration. However, as workers approach the stipulated completion time, they could be under additional pressure due to the amount of work still to be completed within the time remaining to complete that task.

| **Components** | **Your Response in Round 2** | | | **Group Aggregated Response in Round 2** | | | **Retain your response? (Yes/No)** | **If No, provide updated response** | **If final response is two or more units away from group response, please explain why** |
|---|---|---|---|---|---|---|---|---|---|
| | Impact on the time remaining to complete the task? (Yes/No) | Magnitude of Impact | Does the impact increase or decrease the time remaining to complete the task? | Impact on the predictability of the task? (Yes /No) | Magnitude of Impact (median) | Does the impact increase or decrease the time remaining to complete the task? | | | |
| Time available to finish the remaining parts of the task | Choose an item. | Choose an item. | Choose an item. | | | | Choose an item. | Click or tap here to enter text. | Click or tap here to enter text. |
| Need for overtime work to complete task | Choose an item. | Choose an item. | Choose an item. | | | | Choose an item. | Click or tap here to enter text. | Click or tap here to enter text. |

***<u>Additional components suggested by panel members:</u>***

| **Constituent** | **Components** | **Impact on the time remaining to complete the task? (Yes/No)** | **If Yes, how much impact?** | **If No, should it be removed from the list?** | **Does the impact increase or decrease the time remaining to complete the task?** |
|---|---|---|---|---|---|
| Time remaining to complete the task | Opening date | Choose an item. | Choose an item. | Choose an item. | Choose an item. |
| | Deadline penalties | Choose an item. | Choose an item. | Choose an item. | Choose an item. |

**H. Crowding:** Performing work on a construction site requires space to bring in materials and equipment and perform the required work operations. A construction site may become crowded if many multiple crews and/or different trades are required to work in the same area on the project within a specified timeframe. The size and location of the work area available may also increase or decrease the extent of crowding experienced on a project.

| **Components** | **Your Response in Round 2** | | | **Group Aggregated Response in Round 2** | | | **Retain your response? (Yes/No)** | **If No, provide updated response** | **If final response is two or more units away from group response, please explain why** |
|---|---|---|---|---|---|---|---|---|---|
| | Impact on crowding? (Yes/No) | Magnitude of Impact | Does the impact increase or decrease crowding? | Impact on crowding? (Yes /No) | Magnitude of Impact (median) | Does the impact increase or decrease crowding? | | | |
| Many different subcontractors or crews/trades on site at the same time | Choose an item. | Choose an item. | Choose an item. | | | | Choose an item. | Click or tap here to enter text. | Click or tap here to enter text. |
| Many different tasks/activities in the same work area | Choose an item. | Choose an item. | Choose an item. | | | | Choose an item. | Click or tap here to enter text. | Click or tap here to enter text. |
| Size of work area relative to number of workers and size of crew present | Choose an item. | Choose an item. | Choose an item. | | | | Choose an item. | Click or tap here to enter text. | Click or tap here to enter text. |
| Extent of materials and equipment present in the work area | Choose an item. | Choose an item. | Choose an item. | | | | Choose an item. | Click or tap here to enter text. | Click or tap here to enter text. |
| Presence of materials and equipment in the work area | Choose an item. | Choose an item. | Choose an item. | | | | Choose an item. | Click or tap here to enter text. | Click or tap here to enter text. |

***Additional components suggested by panel members:***

| Constituent | Components | Impact on crowding? (Yes/No) | If Yes, how much impact? | If No, should it be removed from the list? | Does the impact increase or decrease crowding? |
|---|---|---|---|---|---|
| Crowding | Unnecessary materials in work area | Choose an item. | Choose an item. | Choose an item. | Choose an item. |
| | Jobsite footprint surrounded by public access streets | Choose an item. | Choose an item. | Choose an item. | Choose an item. |
| | Existing utilities | Choose an item. | Choose an item. | Choose an item. | Choose an item. |

I. **Coordination:** Coordination of the work plays a vital role in executing a construction project since it helps to reduce space and operational conflicts, and enhances teamwork and collaboration. At a task level, coordination might make executing a task more efficient.

| **Components** | **Your Response in Round 2** | | | **Group Aggregated Response in Round 2** | | | **Retain your response? (Yes/No)** | **If No, provide updated response** | **If final response is two or more units away from group response, please explain why** |
|---|---|---|---|---|---|---|---|---|---|
| | Impact on coordination? (Yes/No) | Magnitude of Impact | Does the impact increase or decrease coordination? | Impact on coordination? (Yes /No) | Magnitude of Impact (median) | Does the impact increase or decrease coordination? | | | |
| Amount of pre-planning | Choose an item. | Choose an item. | Choose an item. | | | | Choose an item. | Click or tap here to enter text. | Click or tap here to enter text. |
| Amount of job site management | Choose an item. | Choose an item. | Choose an item. | | | | Choose an item. | Click or tap here to enter text. | Click or tap here to enter text. |
| Quality of job site management | Choose an item. | Choose an item. | Choose an item. | | | | Choose an item. | Click or tap here to enter text. | Click or tap here to enter text. |

***<u>Additional components suggested by panel members:</u>***

| **Constituent** | **Components** | **Impact on coordination? (Yes/No)** | **If Yes, how much impact?** | **If No, should it be removed from the list?** | **Does the impact increase or decrease coordination?** |
|---|---|---|---|---|---|
| Coordination | Crew leader involvement | Choose an item. | Choose an item. | Choose an item. | Choose an item. |
| | Technology | Choose an item. | Choose an item. | Choose an item. | Choose an item. |
| | Quality of details | Choose an item. | Choose an item. | Choose an item. | Choose an item. |

**J. Value of the task:** All tasks on construction projects are valuable since they consume resources and contribute to completion of the project. In addition to the cost and resources used/consumed, the value of a task can vary depending on its complexity, criticality (relative to the critical path), and the type and availability of labor and equipment required to complete the task. Hence, the value of a task could impact a worker's performance on a project.

| **Components** | **Your Response in Round 2** | | | **Group Aggregated Response in Round 2** | | | **Retain your response? (Yes/No)** | **If No, provide updated response** | **If final response is two or more units away from group response, please explain why** |
|---|---|---|---|---|---|---|---|---|---|
| | Impact on the value of the task? (Yes/No) | Magnitude of Impact | Does the impact increase or decrease the value of the task? | Impact on the value of the task? (Yes /No) | Magnitude of Impact (median) | Does the impact increase or decrease the value of the task? | | | |
| Value of task outcome to worker/crew | Choose an item. | Choose an item. | Choose an item. | | | | Choose an item. | Click or tap here to enter text. | Click or tap here to enter text. |
| Value of materials being used and put in place | Choose an item. | Choose an item. | Choose an item. | | | | Choose an item. | Click or tap here to enter text. | Click or tap here to enter text. |
| Value of equipment used for the operation | Choose an item. | Choose an item. | Choose an item. | | | | Choose an item. | Click or tap here to enter text. | Click or tap here to enter text. |
| Significance of task to the timely completion of the project (i.e., on the critical path or not) | Choose an item. | Choose an item. | Choose an item. | | | | Choose an item. | Click or tap here to enter text. | Click or tap here to enter text. |
| Significance of the task to successful completion of the project | Choose an item. | Choose an item. | Choose an item. | | | | Choose an item. | Click or tap here to enter text. | Click or tap here to enter text. |

**K. Interruptions:** While a worker is working on an activity, he/she may need to stop in order to talk with a fellow employee, attend to problems related to the project, replenish material stockpiles, assist an inexperienced crew member, attend to personal business, etc. The interruptions could be internal or external to the project.

| **Components** | **Your Response in Round 2** | | | **Group Aggregated response in Round 2** | | | **Retain your response? (Yes/No)** | **If No, provide updated response** | **If final response is two or more units away from group response, please explain why** |
|---|---|---|---|---|---|---|---|---|---|
| | Impact on interruptions? (Yes/No) | Magnitude of Impact | Does the impact increase or decrease interruption? | Impact interruption? (Yes /No) | Magnitude of Impact (median) | Does the impact increase or decrease interruption? | | | |
| Need to help inexperience crew member | Choose an item. | Choose an item. | Choose an item. | | | | Choose an item. | Click or tap here to enter text. | Click or tap here to enter text. |
| Construction drawings availability | Choose an item. | Choose an item. | Choose an item. | | | | Choose an item. | Click or tap here to enter text. | Click or tap here to enter text. |
| Extent and types of interruptions | Choose an item. | Choose an item. | Choose an item. | | | | Choose an item. | Click or tap here to enter text. | Click or tap here to enter text. |
| Number of overlapping work activities for crew members | Choose an item. | Choose an item. | Choose an item. | | | | Choose an item. | Click or tap here to enter text. | Click or tap here to enter text. |
| Quality of detailed design drawings | Choose an item. | Choose an item. | Choose an item. | | | | Choose an item. | Click or tap here to enter text. | Click or tap here to enter text. |
| Frequent change orders | Choose an item. | Choose an item. | Choose an item. | | | | Choose an item. | Click or tap here to enter text. | Click or tap here to enter text. |

***Additional components suggested by panel members:***

| **Constituent** | **Components** | **Impact on interruptions? (Yes/No)** | **If Yes, how much impact?** | **If No, should it be removed from the list?** | **Does the impact increase or decrease interruptions?** |
|---|---|---|---|---|---|
| Interruptions | Traffic or public access | Choose an item. | Choose an item. | Choose an item. | Choose an item. |

**L.** **Distractions:** While conducting their work tasks, workers may be mentally distracted by the surrounding work conditions, personal interactions with others on or off the jobsite, or other issues of concern. A distraction can be anything that inhibits workers from paying attention to the task or duty (e.g., adverse weather condition).

| **Components** | **Your Response in Round 2** | | | **Group Aggregated Response in Round 2** | | | **Retain your response? (Yes/No)** | **If No, provide updated response** | **If final response is two or more units away from group response, please explain why** |
|---|---|---|---|---|---|---|---|---|---|
| | Impact on distractions? (Yes/No) | Magnitude of Impact | Does the impact increase or decrease distractions? | Impact on distractions? (Yes /No) | Magnitude of Impact (median) | Does the impact increase or decrease distractions? | | | |
| Management control | Choose an item. | Choose an item. | Choose an item. | | | | Choose an item. | Click or tap here to enter text. | Click or tap here to enter text. |
| Experience of supervisor | Choose an item. | Choose an item. | Choose an item. | | | | Choose an item. | Click or tap here to enter text. | Click or tap here to enter text. |
| Deserved positive feedback (compliments) | Choose an item. | Choose an item. | Choose an item. | | | | Choose an item. | Click or tap here to enter text. | Click or tap here to enter text. |
| Noise | Choose an item. | Choose an item. | Choose an item. | | | | Choose an item. | Click or tap here to enter text. | Click or tap here to enter text. |
| Night shifts | Choose an item. | Choose an item. | Choose an item. | | | | Choose an item. | Click or tap here to enter text. | Click or tap here to enter text. |
| More than one language spoken on construction site | Choose an item. | Choose an item. | Choose an item. | | | | Choose an item. | Click or tap here to enter text. | Click or tap here to enter text. |
| Project located in urban area (increased vehicle and pedestrian traffic) | Choose an item. | Choose an item. | Choose an item. | | | | Choose an item. | Click or tap here to enter text. | Click or tap here to enter text. |
| Weather conditions | Choose an item. | Choose an item. | Choose an item. | | | | Choose an item. | Click or tap here to enter text. | Click or tap here to enter text. |

***<u>Additional components suggested by panel members:</u>***

| **Constituent** | **Components** | **Impact on distractions? (Yes/No)** | **If Yes, how much impact?** | **If No, should it be removed from the list?** | **Does the impact increase or decrease distractions?** |
|---|---|---|---|---|---|
| Distractions | Cell Phone Use | Choose an item. | Choose an item. | Choose an item. | Choose an item. |
| | Outside of work distractions (divorce, arguments, traffic accidents, etc.), | Choose an item. | Choose an item. | Choose an item. | Choose an item. |
| | Remote project sites/away from family | Choose an item. | Choose an item. | Choose an item. | Choose an item. |

**M. Pace of task:** Productivity is an important factor that drives work execution. The pace of the work is considered as the time taken to perform a specified amount of work. A faster pace of work means more work is being accomplished in a given period of time.

| **Components** | **Your Response in Round 2** | | | **Group Aggregated Response in Round 2** | | | **Retain your response? (Yes/No)** | **If No, provide updated response** | **If final response is two or more units away from group response, please explain why** |
|---|---|---|---|---|---|---|---|---|---|
| | Impact on the pace of the work? (Yes/No) | Magnitude of Impact | Does the impact increase or decrease the pace of the work? | Impact on pace of task? (Yes /No) | Magnitude of Impact (median) | Does the impact increase or decrease the pace of the work? | | | |
| Time available to finish the remaining parts of the task | Choose an item. | Choose an item. | Choose an item. | | | | Choose an item. | Click or tap here to enter text. | Click or tap here to enter text. |
| Need for overtime work to complete task | Choose an item. | Choose an item. | Choose an item. | | | | Choose an item. | Click or tap here to enter text. | Click or tap here to enter text. |

**N. Switching between tasks:** Some workers may be assigned multiple tasks to perform in a given shift. In some cases the timing of the tasks may overlap. Switching between tasks occurs when a worker attempts to go from one task to another to accomplish both tasks during the same time period. Switching may also occur when a worker is given new tasks very frequently during the work shift.

| **Components** | **Your Response in Round 2** | | | **Group Aggregated response in Round 2** | | | **Retain your response? (Yes/No)** | **If No, provide updated response** | **If final response is two or more units away from group response, please explain why** |
|---|---|---|---|---|---|---|---|---|---|
| | Impact on switching between tasks? (Yes/No) | Magnitude of Impact | Does the impact increase or decrease switching between tasks? | Impact on switching between tasks? (Yes /No) | Magnitude of Impact (median) | Does the impact increase or decrease switching between tasks? | | | |
| Multi-tasking | Choose an item. | Choose an item. | Choose an item. | | | | Choose an item. | Click or tap here to enter text. | Click or tap here to enter text. |
| Rate in which new tasks are given | Choose an item. | Choose an item. | Choose an item. | | | | Choose an item. | Click or tap here to enter text. | Click or tap here to enter text. |
| Frequency of substituting for crew member (due to absence, for instance) | Choose an item. | Choose an item. | Choose an item. | | | | Choose an item. | Click or tap here to enter text. | Click or tap here to enter text. |

***Additional components suggested by panel members:***

| **Constituent** | **Components** | **Impact on switching between tasks? (Yes/No)** | **If Yes, how much impact?** | **If No, should it be removed from the list?** | **Does the impact increase or decrease switching between tasks?** |
|---|---|---|---|---|---|
| Switching between tasks | Errors and forgotten steps | Choose an item. | Choose an item. | Choose an item. | Choose an item. |
| | Changed condition | Choose an item. | Choose an item. | Choose an item. | Choose an item. |
| | lack of planning | Choose an item. | Choose an item. | Choose an item. | Choose an item. |

2- Please provide any comments or suggestions related to *Metrics* for each component. Feel free to also suggest additions, deletions, or modifications to any of the components.
   Click or tap here to enter text.

Thank you for completing Round 3 of the survey. We very much appreciate your time devoted to the study.

**Please send your completed survey questionnaire file to the researchers via email using the email addresses below.**

If you have any questions and/or concerns related to the research study, please do not hesitate to reach us at the following email addresses:

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## Round 4: Confirm and Finalize Energy Quantification

### Part I: Confirm Case Scenarios for Four Constituents

Part I is intended to clarify and confirm responses received in Round 3 related to four of the energy constituents.

1. Based on your experience, please indicate your level of agreement with the following questions regarding whether the constituent has an increasing or decreasing impact on energy.

   A. **Availability of needed resources:** Resources (e.g., materials, equipment, labor, etc.) are a significant part of all construction projects, and resource availability is a critical factor for the work to be accomplished.

   *"If the exact materials or tools that a worker needs to execute the task are readily available, the level of energy felt by the worker will decrease."*
   To what extent do you agree that an increase in the availability of needed resources decreases the level of energy felt by a worker?

   ☐ 5: Strongly agree
   ☐ 4: Agree
   ☐ 3: Somewhat agree
   ☐ 2: Disagree
   ☐ 1: Strongly disagree
   ☐ 0: I do not know
   ☐ Other, please specify: Click or tap here to enter text.

   B. **Crowding:** Performing work on a construction site requires space to bring in materials and equipment and perform the required work operations. A construction site may become crowded if many multiple crews and/or different trades are required to work in the same area on the project within a specified timeframe. The size and location of the work area available may also increase or decrease the extent of crowding experienced on a project.

   *"If many different subcontractors, workers, or crews/trades are on site at the same time, the energy felt by a worker will increase."*

To what extent do you agree that an increase in crowding increases the level of energy felt by a worker?

☐ 5: Strongly agree

☐ 4: Agree

☐ 3: Somewhat agree

☐ 2: Disagree

☐ 1: Strongly disagree

☐ 0: I do not know

☐ Other, please specify: Click or tap here to enter text.

C. **Distractions:** While conducting their work tasks, workers may be mentally distracted by the surrounding work conditions, personal interactions with others on or off the jobsite, or other issues of concern. A distraction can be anything that inhibits workers from paying attention to the task or duty (e.g., adverse weather conditions).

*"If the worker is distracted by surrounding work conditions or other ongoing operations, the energy felt by the worker will increase."*

To what extent do you agree that an increase in worker distractions increases the level of energy felt by the worker?

☐ 5: Strongly agree

☐ 4: Agree

☐ 3: Somewhat agree

☐ 2: Disagree

☐ 1: Strongly disagree

☐ 0: I do not know

☐ Other, please specify: Click or tap here to enter text.

☐ Other, please specify: Click or tap here to enter text.

D. **Switching between tasks**: Some workers may be assigned multiple tasks to perform in a given shift. In some cases the timing of the tasks may overlap. Switching between tasks occurs when a worker attempts to go from one task to another to accomplish both tasks during the same time period. Switching may also occur when a worker is given new tasks very frequently during the work shift.

*"When the frequency in which a worker switches between multiple tasks on site increases, the level of energy felt by the worker also increase."*

To what extent do you agree that an increase in switching between tasks increases the level of energy felt by a worker?

☐ 5: Strongly agree

☐ 4: Agree

☐ 3: Somewhat agree

☐ 2: Disagree

☐ 1: Strongly disagree

☐ 0: I do not know

☐ Other, please specify: Click or tap here to enter text.

## Part II: Confirm Energy Quantification

In this part of the survey, you will be asked to review and confirm the energy model that has been developed to calculate the level of "energy" that a worker feels when conducting work on a construction site. Please review the energy model calculations provided in the Excel spreadsheet before answering the questions below.

2. Based on your work experience and involvement in the previous rounds of this survey, please answer the following questions indicating your level of agreement with the results of this study.

   A. To what extent do you agree that the overall **energy model** could be applied to measure the level of energy associated with a task(s) on a construction site?

      ☐ 5: Strongly agree
      ☐ 4: Agree
      ☐ 3: Somewhat agree
      ☐ 2: Disagree
      ☐ 1: Strongly disagree
      ☐ 0: I do not know
      ☐ Other, please specify: Click or tap here to enter text.

   B. To what extent do you agree that **Kinetic Energy (KE)** can be used as a means to accurately reflect the level of "energy" experienced by workers while performing work?

      ☐ 5: Strongly agree
      ☐ 4: Agree
      ☐ 3: Somewhat agree
      ☐ 2: Disagree
      ☐ 1: Strongly disagree
      ☐ 0: I do not know
      ☐ Other, please specify: Click or tap here to enter text.

C. To what extent do you agree that **Potential Energy (PE)** can be used as a means to accurately reflect the level of "energy" experienced by workers who are assigned work that is yet to be executed?

☐ 5: Strongly agree
☐ 4: Agree
☐ 3: Somewhat agree
☐ 2: Disagree
☐ 1: Strongly disagree
☐ 0: I do not know
☐ Other, please specify: Click or tap here to enter text.

D. To what extent do you agree that the **constituents** shown in the Excel spreadsheet can be used as a means to accurately measure the level of energy associated with a task(s) on a construction site?

☐ 5: Strongly agree
☐ 4: Agree
☐ 3: Somewhat agree
☐ 2: Disagree
☐ 1: Strongly disagree
☐ 0: I do not know
☐ Other, please specify: Click or tap here to enter text.

E. To what extent do you agree that the **components** shown in the Excel spreadsheet can be used as a means to accurately measure each constituent?

☐ 5: Strongly agree
☐ 4: Agree
☐ 3: Somewhat agree
☐ 2: Disagree
☐ 1: Strongly disagree
☐ 0: I do not know
☐ Other, please specify: Click or tap here to enter text.

F. An initial **metric** scale has been developed for each component using a linear scale (e.g., 1, 2, 3, 4, 5). To what extent do you agree that the scale values are appropriated for each level in the metric to measure each component?

☐ 5: Strongly agree
☐ 4: Agree
☐ 3: Somewhat agree

☐ 2: Disagree
☐ 1: Strongly disagree
☐ 0: I do not know
☐ Other, please specify: Click or tap here to enter text.

G. To what extent do you agree that the **energy model** shown in the Excel spreadsheet will accurately reflect the **safety** performance of a worker while performing a construction task?

☐ 5: Strongly agree
☐ 4: Agree
☐ 3: Somewhat agree
☐ 2: Disagree
☐ 1: Strongly disagree
☐ 0: I do not know
☐ Other, please specify: Click or tap here to enter text.

H. To what extent do you agree that the **energy model** shown in the Excel spreadsheet will accurately reflect the level of work **quality** produced by a worker when conducting a work task?

☐ 5: Strongly agree
☐ 4: Agree
☐ 3: Somewhat agree
☐ 2: Disagree
☐ 1: Strongly disagree
☐ 0: I do not know
☐ Other, please specify: Click or tap here to enter text.

I. To what extent do you agree that the **energy model** shown in the Excel spreadsheet can be used to accurately measure other performance criteria such as productivity, cost, etc.?

☐ 5: Strongly agree
☐ 4: Agree
☐ 3: Somewhat agree
☐ 2: Disagree
☐ 1: Strongly disagree
☐ 0: I do not know

☐ Other, please specify: Click or tap here to enter text.

3. Please provide any additional comments or suggestions related to the formulation of the energy model and values. Feel free also to suggest additions, deletions, or modifications to any of the formulas presented above.
   Click or tap here to enter text.

Thank you for completing Round 4 of the survey. We very much appreciate your time devoted to the study.

If you have any questions or concerns related to the research study, please do not hesitate to reach us at the following email addresses:

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Appendix B: Data Collection form Literature Review and Survey Questionnaire.

Appendix $B_1$: Expert Panelists Demographics

| Panelists | Degree | Organization(s) | Job Title | Years | Professional Registration | Member of Committee | Number of employees and/or students | Publications | Presentations | Leading Positions |
|---|---|---|---|---|---|---|---|---|---|---|
| **P1** | BSc | Owner Organization | Project Manager | 17 | APEG BC | - | 100 employees | - | 2 | Risk Superintendent and Principal Studies. |
| **P2** | PhD | University | Faculty Member, Construction Firm | 14 | ASCE, ASSP, NFPA, AIHA, ACGIH, RIMS. | ASSP Education Committee | 15 employees, all safety professionals during my time in the industry | Academic journal paper 30, Book or book chapter 3, Conference paper 6, Industry publication (e.g., technical report) 4 | 40+ | Assistant/ Associate Professor, Safety and Health Management and EHS Program Manager. |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **P3** | PhD | University | Faculty Member | 14 | ASCE, ASSP. | CII Community of Practice Chair, Technical advisor for EEI and INGAA, Associate Editor of Safety Science, ASCE site safety committee; ASSP technical publications committee; ASSP research committee | 60 students | Academic journal paper 80, Book or book chapter 4, Conference paper 65, Industry publication (e.g., technical report) 12 | >100 | Professor, Research Assistant and Consultant and expert witness. |
| **P4** | BSc | Construction Firm | Project Manager | 13 | - | - | Nine employees | - | 3 | Field Engineer, Project Engineer, and Project Manager. |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **P5** | BSc | Owner organization | Owner's Representative | 12 | Oregon EIT, LSIT | - | 25 employees | - | - | Construction Inspector, Construction Coordinator, Land Development Design, and Surveying Engineering Associate. |
| **P6** | BSc | Construction Firm | Safety Engineer | 14 | ASSP, FE registration on WA State, ASME member | Environmental, Health, & Safety Chair - OCAPA | 1500 employees | Academic journal paper 3 | 20 | Safety Manager, Mine Inspector/ Accident Investigator, and general Engineer – 6 years |
| **P7** | High School Diploma | Construction Firm | Executive Manager | 24 | Safety Advisory board, APAO | AGC Oregon, APAO EX. Board, NAPA Advisory board, ODOT | 100's of Employees, 10-15 Internship | - | 1 | Superintendent and operations manager |

| | | | | | | | | | | |
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| | | | | | Ex. Board | Safety Advisory Board | | | | |
| **P8** | BS | Construction Firm | Safety Engineer | 18 | NSC National Safety Council | - | 1000 employees | Academic journal paper 2 | Multiple pieces of training for OSHA 30 | Construction Laborer, Safety Manager |
| **P9** | MSc | Design and Construction Firm | Design Engineer | 18 | ASCE, SEA RI, AISC. | ASCE Safety Committee, ASCE RI Section, ASCE Collaborate Editorial Board | 1-2, Engineers in Training | - | One presentation for SEA RI | Miscellaneous steel detailer and design engineer |
| **P10** | Community College | Construction Firm | Safety Engineer | 35 | ASSP | ASSP Columbia Willamette Chapter President | 10 to 15 students from OSU, MHCC, and CWU. 25 safety managers. | Conference paper 1 | 2 | Four positions same roll |

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| **P11** | MSc | Construction Firm | Project Manager | 4 | - | - | - | - | - | - |
| **P12** | BSc | Construction Firm | Project Manager | 23 | - | - | 100 employees | - | - | - |
| **P13** | High School Diploma | Construction Firm | Safety Engineer | 28 | ASSP, BCSP | ASSP – Chair-Elect, Vice-Chair, Chair, Past Chair Construction Safety Summit – Co-Chair for seven years. | 60 employees | - | 20 Conference sessions | Field Employee (general labor, equipment operator), Field Manager (Foreman/ superintendent), Safety Manager, and Company Owner. |
| **P14** | Journeyman Electrician | Construction Firm | Upper Management (President, COE, Vice President, or other | 25 | - | Safe build Alliance - President | Estimators 20+, Project Managers 30+ and Electrical Field Leaders 50+ | - | - | - |

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| **P15** | MSc | Construction Firm | Project Engineer | 2.5 | - | Quality, schedule | Train 3 new project engineers | - | - | - |
| **P16** | BSc | Construction Firm | Upper Management (President, COE, Vice President, or other | 15 | ASSP | ASSP and Safe build Alliance | 10,000 craft workers, 17 safety professionals | - | 3 | Safety Administrator, Field Superintendent, Safety Representative, Corporate Safety Manager, and Director of Safety. |

Appendix $B_2$: Components for Each Constituent

| No. | Constituents | Components | Authors |
|---|---|---|---|
| 1 | Complexity of the task | Task size | (Dewar and Hage 1978) |
| | | Task budget | (Hirst and Yetton 1999) |
| | | Pre-planning | (Yua and Ellis 2003; Ghavamnia et al. 2013) |
| | | Task execution | (Topcuoflu et al. 2002) |
| | | Number of steps | (Christian and Kalle 2012) |
| | | Level of physical strain/exertion | (Kakarot and Müller 2014) |
| | | Resources | The Delphi panel members |
| | | Limited accessibility | |
| | | Adverse weather and environment | |
| 2 | Uniqueness of the task | Special skills/experience needed to perform the task(s) | (Romo 2013) |
| | | Task new to worker | (Shikdar and Das 2003) |
| | | Task new to the industry | |
| | | Task new to the project/company | |
| | | Proper training to new/unique task | The Delphi panel members |
| | | Familiarization with tools for unique task | |
| | | Use of proprietary products | |
| | | Job specifications | |
| 3 | Predictability of the task | Uncertainty about task scope and performance at the start | (Rai and Hindi 2000) |
| | | Uncertainty about task scope and performance during execution of the task | |
| | | Task duration is not predictable | (Boltz 1998) |
| | | Available data/risk analysis | The Delphi panel members |

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| | | Means and Methods available | |
| 4 | Repetitiveness of the task | Task is performed more than once | (Ford, Quiñones, Sego, and Sorra 1992) |
| | | Task duration is long | (Burt and Kemp1994) |
| | | Task is continuous | |
| | | Listening to the radio | The Delphi panel members |
| 5 | Availability of needed resources | Presence of materials and tools | (Tukel and Rom 1998) |
| | | Presence of appropriate equipment storage | |
| | | Familiarity with the materials and equipment | (Espinosa et al. 2007) |
| | | Quality of material, tools, and equipment | (Karbhari, Slotte, Steenkamer, and Wilkins, D. J. 1992). |
| | | Presence of labor force/crew members who can perform the task | (Olomolaiye et al., 1996; Rojas and Aramvareekul, 2003; Motwani et al., 1995). |
| | | Presence of capable supervisor | (Nguyen, and Watanabe 2017). |
| | | Availability of PPE | (Khaqiiqudin, Wahyuni, Kurniawan and 2019) |
| | | Cost of materials | The Delphi panel members |
| | | Traffic and delivery | |
| 6 | Duration of the task | Time required to complete the task | (Peurifoy and Ledbetter 1985) |
| | | Time available to complete the task | |
| | | Availability of a buffer | (Russell et al. 2014) |
| | | Knowledge of the schedule | The Delphi panel members |
| | | Special tools | |
| 7 | Time remaining to complete the task | Time available to finish the remaining parts of the task | (Hanna et al. 2005) |
| | | Need for overtime work to complete a task | |
| | | Opening date | The Delphi panel members |
| | | Deadline penalties | |

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| 8 | Crowding | Many different subcontractors or crews/trades on-site at the same time | (Dozzi and AbouRizk, 1993) |
| | | Many different tasks/activities in the same work area | |
| | | Size of work area relative to number of workers and size of crew present | |
| | | The extent of materials and equipment present in the work area | (Sacks et al., 2009) |
| | | Presence of materials and equipment in the work area | |
| | | Unnecessary materials in work area | The Delphi panel members |
| | | Jobsite footprint surrounded by public access streets | |
| | | Existing utilities | |
| 9 | Coordination | Amount of pre-planning | (Hossain 2008) |
| | | Amount of job site management | Crowston (1994) |
| | | Quality of job site management | (Pentland 1994; Malone et al., 1993) |
| | | Crew leader involvement | The Delphi panel members |
| | | Technology | |
| | | Quality of details | |
| 10 | Value of the task | Value of task outcome to worker/crew | (Pereira et al., 2018) |
| | | Value of materials being used and put in place | (Hendrickson 1998) |
| | | Value of equipment used for the operation | |
| | | Significance of the task to the timely completion of the project (i.e., on the critical path or not) | (Nnaji 2015) |
| | | Significance of the task to successful completion of the project | |
| | | Better alternative approaches available | The Delphi panel members |
| 11 | Interruptions | Need to help an inexperience crew member | (Mitropoulos and Memarian 2012) |
| | | Construction drawings availability | (Akinci et al., 2006) |
| | | Quality of detailed design drawings | |
| | | Number of overlapping work activities for crew members | (Dozzi and AbouRizk, 1993) |

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|---|---|---|---|
| | | Extent and types of interruptions | (Jett and George 2003) |
| | | Frequent change orders | (Shrestha et al. 2017) |
| | | Traffic or public access | The Delphi panel members |
| 12 | Distractions | Management control | (Namian et al. 2018) |
| | | Experience of supervisor | |
| | | Deserved positive feedback (compliments) | (Nnaji and Gambatese 2016) |
| | | Noise | (Ke et al., 2019) |
| | | Night shifts | |
| | | More than one language spoken on construction site | (Oswald et al., 2019) |
| | | Project located in an urban area (increased vehicle and pedestrian traffic) | (Reed et al., 2018) |
| | | Weather conditions | (Nnaji and Gambatese 2016) |
| | | Cell Phone Use | The Delphi panel members |
| | | Outside of work distractions (divorce, arguments, traffic accidents, etc.), | |
| | | Remote project sites/away from family | |
| 13 | Pace of the task | Production rate (e.g., ft/hr., cy/hr., etc.) | (Nnaji and Gambatese 2016) |
| | | Rework frequency | (Chiu et al., 2019; Love et al., 2018) |
| 14 | Switching between tasks | Multi-tasking | (Tregubov et al. 2017) |
| | | Rate in which new tasks are given | (Meiran and Daichman 2005) |
| | | Frequency of substituting for crew member (due to absence, for instance) | Nicholson et al., 2006 |
| | | Errors and forgotten steps | The Delphi panel members |
| | | Changed condition | |
| | | lack of planning | |