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Using workers compatibility to predict labor productivity through cluster analysis

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Abstract

Masonry contractors seek to increase labor productivity by collecting detailed information on the workers productivity and the factors that influence productivity. Quantitative factors such as hours, activities, and tasks are often measured on site and are used to estimate productivity and determine times of construction. However, there may be qualitative factors such as personality that may also need to be measured on site because it can have a profound impact on the productivity of a crew. This paper proposes a mathematical framework that uses the personal compatibility between the workers in a crew to better estimate productivity. An instrument to measure and quantify personality is proposed to determine the compatibility of the workers in a crew. Cluster analysis principles are applied to group crews that share similar compatibility and productivity scores and use this information to empirically define a probability density function that will determine, for a given cluster, its average productivity. To illustrate how the function is used to predict the productivity of a crew, this paper presents an example applied in masonry construction in which times of construction and productivity are determined using the personal compatibility between the workers in the crew.

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1. Introduction

Personality factors have been demonstrated to be useful for explaining and predicting attitudes, behaviors, job performance, and outcomes in many organizational settings (Ones et al, 2007; Shuck and Reio, 2013; Hogan and Holland, 2003; Campion et al, 2005; Cohen and Bailey, 1997). The big five personality dimensions (Goldberg, 1993) are: openness to experience (O), conscientiousness (C), extraversion (E), agreeableness (A), and neuroticism (N), commonly known as OCEAN, and are used to indicate human personality (Ones et al, 2007). The OCEAN dimensions have been investigated in meta-analytic studies (Hogan and Holland, 2003; Cohen and Bailey, 1997), and have been used in applied psychology and human resource management to determine the relationship between personality and job performance. Results of these studies have shown that organizations use personality factors not only for recruitment and personnel selection, but also to support decision making when forming effective groups of workers (Kristof-Brown and Stevens, 2001).

In construction, groups of workers are known as crews. Crews specialize in a given skill to complete a task (Ng and Tang, 2010), and the foreman in the jobsite is responsible of forming crews to maximize productivity. Decisions on how to form crews and what is the proper grouping of workers to increase productivity in construction have been addressed by a number of studies (Nerwal and Abdelhamid, 2012; Mitropoulos and Memarian, 2012; Rojas 2008). These studies provide clear guidelines and specific characteristics that need to be considered to form lean and effective crews.

However, the current crew formation literature in construction lacks of a framework that considers personality factors and how the interpersonal compatibility between workers in a crew can be used to predict productivity. This paper proposes a mathematical framework that uses the personal compatibility between the workers in a crew to better estimate productivity. An instrument to measure and quantify personality is proposed to determine the compatibility of the workers in a crew. Cluster analysis principles are applied to group crews that share similar productivity values and use this information to empirically define a probability density function (PDF). The PDF determines, for a given cluster, the average productivity. The proposed PDF can enable foremen and project managers to use the information from the clusters to make more realistic predictions, by calculating confidence intervals, of the productivity of a crew and to better estimate times of construction.

2. Personality factors

2.1. The Big Five personality dimensions

It is well known that group work is organized by determining what will be done and who will do it, and in this process, group members make a big effort to get along (Mach and Baruch, 2015). In order to get along with a group, people cooperate and seem compliant, friendly, and positive, and people that get along usually have similar personality factors. The big five personality dimensions (Goldberg, 1993) are: openness to experience (O), conscientiousness (C), extraversion (E), agreeableness (A), and neuroticism (N), commonly known as OCEAN. Openness (O) describes the breadth, depth and complexity of an individual's mental and experiential life. Conscientiousness (C) describes socially prescribed impulse control that facilitates task and goal-directed behaviour. Extraversion (E) summarizes traits related to activity and energy, dominance, sociability, expressiveness, and positive emotions. Agreeableness (A) contrasts a prosocial orientation toward others with antagonism and includes traits such as altruism, kind mindedness, trust, and modesty. Neuroticism (N) contrasts emotional stability with a range of negative affects including anxiety, sadness, irritability, and nervous tension (John et al, 1991).

This five factor structure is used to describe human personality (Ones et al, 2007) and can capture much of the variance in personality trait ratings. The OCEAN dimensions do not imply that personality differences can be reduced to five traits (Goldberg, 1993), rather they represent personality at the broadest level of abstraction. Each dimension includes a large number of distinct more specific personality characteristics that help to create the taxonomy of personality. The big five personality dimensions OCEAN have been used in meta-analytic reviews in applied psychology since personality factors are useful predictors of job performance (Hogan and Holland, 2003).

2.2. Personal compatibility

A number of studies have demonstrated that personality factors influence the compatibility of a group (Kristof-Brown and Stevens, 2001; Witt, 1998). Compatibility reflects the tendency of a group to have similar ways to work, get along well, get things done, and facilitate group performance (Kristof-Brown and Stevens, 2001). In compatible groups, workers are more willing to communicate, share information, and resolve conflicts effectively, which translates in increased job performance and productivity (Dineen et al, 2002). In other words, a compatible group is a team in which the characteristics of its workers have been well matched (Kristof-Brown and Stevens, 2001). In this case, a compatible group is a crew in which the masons get along well and can work well together and have better productivity rates. The next section illustrates how to quantify personality and compatibility.

2.3. Instrument to measure personality and compatibility

There are a number of tests that can be used to indicate personality factors using the Big Five model. These tests are used to allow efficient and flexible assessment of the five dimensions and have also been used in meta-analysis to determine workers' personality factors to evaluate their fit or compatibility with a group (Kristof-Brown et al, 2005; Burch and Anderson, 2004). Personality tests are not only designed to classify humans based on their personal characteristics, but also are widely used to select personnel and form effective groups (Dineen et al, 2002). One of such tests is the Belbin test, which is used to form successful groups based on personality traits and roles that each person may contribute to the group (Belbin, 2017). Another is the Myers-Briggs test, which is used to classify personality preference types and identify how people make decisions (Rojas, 2008). These tests have been extensively used in applied psychology and allow managers to identify personal characteristics, quantitatively measure personality and use this information to form compatible groups of workers (Hobman et al, 2003).

Because single trait adjectives are responded less consistently that when they are accompanied by definitions or descriptions, the big Five test does not use single adjectives as items, rather it uses one or two typical adjectives as the item to which more clarifying information is added to gather responses from participants. The five dimensions of human personality are measured using an instrument similar to the instrument shown below (see Table 1).

Table 1. Personality measurement instrument

Personality dimension	Item number	Personality statement
Openness	*P1*	is original, comes up with new ideas
Conscientiousness	*P2*	perseveres until the task is finished
Extraversion	*P3*	is talkative
Agreeableness	*P4*	is helpful and unselfish with others
Neuroticism	*P5*	can be tense

The adjective pairs (P1-P5) used to measure openness to experience, conscientiousness, extraversion, agreeableness, and neuroticism items deployed for this instrument are based on associated wording of personality characteristics derived from John et al (1991). In order to indicate human personality and to better understand the factors that could influence the compatibility of a crew, a questionnaire was conducted among the construction workers in a building site. The questionnaire presented the statements outlined in Table 1. Workers were instructed to first examine the statements and to think about whether it describes their personality traits or characteristics, that is, determine whether each statement applies or not to them. The subjects are asked to think about their personality and mark a score on a 5-point Likert scale (1=disagree strongly, 2=disagree a little, 3=neither agree nor disagree, 4=agree a little, 5=agree strongly) to the statements asked. The statements included were each of the personality statements in Table 1. For instance, one question asks respondents if they see themselves as someone who is talkative on the 5-point Likert scale. Approximately half of the measurement items are reversed to reduce response bias.

3. Predicting Productivity

3.1. Mathematical framework

Figure 1 shows the mathematical framework that supports masonry contractors in the process of defining the probability function to predict productivity. The data input module determines the personality OCEAN factors and based on these factors an instrument is developed to identify personality. In the measurement module, masons complete the instrument (see Table 1) to indicate their personality. After collecting the responses to the questionnaire, a personality score is determined which accounts for the OCEAN dimensions and helps determine personality traits of the workers. This personality score is then combined to quantify the compatibility of a crew by means of a matrix. Given a crew, file j of this matrix will account for the scores obtained by the j-th mason of the crew (an arbitrary order will be given for the masons in the crew and this should not affect the output of the method), and in each of the spaces of this file the scores will be recorded.
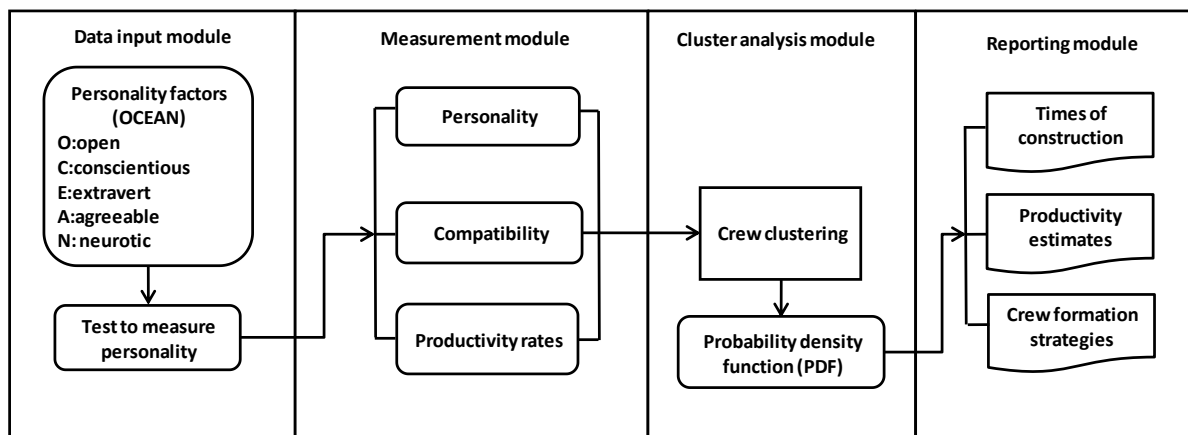

Figure 1. Mathematical framework

In the cluster analysis module, the relation between productivity and compatibility can be identified, that is, crews that have the similar productivity will be clustered together and a probability density function (PDF) that predicts productivity will be determined for each cluster. Based on experiments on the field, matrices with similar productivity will be grouped together, in what we shall call a cluster. After the clusters have been defined, a probability density function for the productivity of the cluster is defined. This part we call calibration. Once this calibration has been made, we are ready to apply it to a new situation. To predict the productivity for a crew, we look at its matrix, then find the cluster it is closest to and assign to this crew the productivity (which is actually given by a PDF) associated to the cluster. An interesting and important question is how this closeness is to be determined; this can be done by identifying some common features to the matrix in a cluster which can be quantified. For instance, the distance could be the ratio of the smallest to the largest eigenvalue of the matrix obtained by multiplying the transpose of the original compatibility matrix by the compatibility matrix).

Once it has been quantified, the process is to find the cluster (with a given compatibility) closest to the same compatibility of the matrix under examination. Note that the assumption is that similar characteristics will give similar productivities, and again this would require some testing on the field. Having the productivity, we can then use Florez (2015) model to better estimate the times of construction. However, in the best case scenario all we can assume is that productivity is actually a random variable, so for a given cluster the best we can have is a probability density function for the productivity of the cluster. This uncertainty is then quantified and allows predicting time frames for the construction with probability estimates attached to it.

With the function, foremen and project managers can better predict productivity rates and estimate times of construction. In other words, by only using the compatibility of a crew of workers, more accurate predictions can be made of the productivity of a crew, the times of construction and strategies for crew formation (see Reporting module).

3.2. An example to predict productivity and estimate times of construction

Once we have a productivity associated to a compatibility matrix, which is also associated to a compatibility score, we proceed to use the model as follows. Given the probability density function (PDF) that gives the productivity of any given crew of a given compatibility score (so always think of the productivity as a random variable), to define a productivity function we use the average given by the PDF, and introduce these values into the model which in turn will give an optimal scheduling. However, since the productivity of a crew is a random variable, there is uncertainty regarding how long it will take to complete the job. To see how to use the fact that the productivity is actually a random variable, let us show an example. Assume that the model shows that the job can be cleanly divided into two blocks. In other words, there are two sets of walls, say W_1 and W_2, so that W_2 will start as soon as all the walls in the set W_1 are finished, and that the walls in each set are simultaneously built. Then it is easy to compute the probability of finishing the job within a certain window of time from the result given by the model. So we let the walls in W_1 be numbered as w_{1j}, $j = 1, 2, \ldots, n$, and the walls in the set W_2 be numbered as w_{2i}, $i = 1, 2, \ldots, m$. As the model has already been run, we know that to each wall in each set a crew has been assigned, and hence there is now a PDF associated to each wall that determines the time it will take to complete the job. Let's assume that we know the mean and the variance of each PDF, and considering maximum entropy, it is natural to assume that the PDF's are normal distributions. So for the wall w_{su}, its construction time is a random variable T_{su}, whose PDF, which encodes the time it takes to build, is given:

$$P_{su}(t) = \frac{1}{\sqrt{2\pi}\sigma_{su}} \exp\left(\frac{(t - \mu_{su})^2}{2\sigma_{su}^2}\right)$$

where μ_{su} and σ_{su} are the mean and variance associated for the construction time of wall u in set s. Note that the mean and variance are obtained empirically for a crew with a certain compatibility matrix (or score), so it has been estimated on site and it is assumed to be universal for any crew with this compatibility matrix (or score).

Now we use the assumption that to start with the walls in W_2 we must finish with all the walls in W_1, and that the walls in each set can be built simultaneously. This allows us to use order statistics, as all we need to solve the problem is to find the PDF of the random variable that gives the maximum time of construction of any wall in the set. We shall denote this random variables by Z_k, $k = 1, 2$, one for each set of walls. As it has been described, these random variables are given by:

$$Z_1 = \frac{\max}{j = 1, 2, \ldots m} T_{1j} \qquad Z_2 = \frac{\max}{j = 1, 2, \ldots m} T_{2i}$$

There are formulas and approximations to compute this order statistics for a set of normal distributions. But as we will not use them here, we will avoid writing them down. What matters to us now is that Z_1 and Z_2 are independent random variables, and so the distribution we need to compute now is the distribution of $Z_1 + Z_2$, which is the convolution of the PDF's obtained for each Z_1 and Z_2. With this PDF we can then find intervals of confidence that will tell us with a given probability how long it will take to finish the job.

4. Discussion

A number of meta-analytic studies have been carried out, indicating the use of personality factors for explaining and predicting attitudes, behaviours, well-being, job performance, and outcomes in many organizational settings.

Although a number of outcomes have been predicted using personality characteristics, there are a limited number of studies that have used personality factors to predict the productivity of a construction crew. Therefore, a study that relates compatibility and productivity is needed to support the current decision making process of forming crews in building sites by considering personality characteristics and the personal compatibility of the workers.

The instrument of personality to be deployed in this study alongside the productivity function can help assess personal characteristics of workers and bring significant positive changes to the actual process of crew formation in construction sites. Its usefulness lies in the opportunity to include in the decision-making process subjective characteristics associated with workers. The assessment of personality characteristics may help capture the characteristics of workers and help determine the compatibility between the workers in a crew. Therefore, project managers and foremen can use compatibility to better predict productivity and reduce crew conflicts. Through a questionnaire, the benefits of understanding and capturing the personal characteristics of a worker could be realized. Personality features may broaden the capabilities of the decision making process by allowing project managers and foremen to use personal characteristics for forming crews. As a result, the process of crew formation may be simplified while incorporating personality, which has proven to be a critical factor that influences productivity.

The proposed productivity distribution incorporates personality measures to assist decision making in crew formation. The instrument of personality characteristics provides a quantitative assessment of the compatibility of a crew resulting from the collection of personal characteristics from the worker's perspective. The compatibility between the workers in a crew is used to quantify productivity and should be useful for foremen to better estimate times of construction and identify effective crew formations. In addition to the personal characteristics, the compatibility of the crew will be calculated and it will be used to determine its relation with productivity, that is, compatibility will be used to make more accurate estimates of the productivity of a crew. Additionally, guidelines will be determined to assist decision makers on the optimal composition of a crew.

As information about labor productivity increases, the factors that influence productivity in construction sites expands overwhelming project managers and foremen with information and making the retrieving and efficient use of information process effortful. Therefore, it is necessary to understand the personal characteristics of workers in order to help foremen benefit from all the information provided and maximize the strengths of its workers. The instrument to be deployed in this study may contribute to benefit the formation of crews in construction and other organizations. By investigating if compatibility can be used to better estimate productivity, workers information could become valuable information to assist the process of forming and allocating crews in construction sites. The understanding of personality characteristics within building construction enhances workforce management contributing on how to better utilize the available workers to more precisely estimate total project costs and increase productivity.

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