Computerizability, Consequence of Error, and Job Automation

Emergent Research Forum (ERF) Paper

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Abstract

Job automation is a critical decision to make and has brought significant changes to workplaces. However, what job characteristics make a job suitable for automation has not always been clear. In this study, we propose a research framework that includes two key contributing factors for job automation: computerizability and consequence of error. We further leverage the US O*NET database on job characteristics to validate this framework. The results strongly support the framework, showing that job automation needs to take into consideration the ease to automate and the cost and benefit of automation.

Keywords: Job automation, computerizability, task variety, task analyzability, consequence of error

Introduction

Automation has been defined as the performance of tasks or functions by machines (usually computers) rather than human operators (Parasuraman and Riley 1997; Parasuraman et al. 2000). Automation dates back at least to the first Industrial Revolution, but large-scale automation starts during the early 20th century when Henry Ford introduced the assembly lines for mass production. Now with the advance of information technology (IT), and artificial intelligence in particular, many jobs are becoming increasingly performed by computer-controlled machines. Given the technical capabilities of computer hardware and software, a critical question that both practitioners and researchers face today is what jobs should be automated and to what extent?

As a general rule, automation involves task allocation between humans and machines, so that tasks that can be performed better by machines should be automated, whereas those that humans do better should not. In other words, machines should execute such jobs or functions that humans do not wish to perform or cannot perform as accurately or reliably as machines (Parasuraman et al. 2000), and human interventions are necessary where machines cannot perform as well so that human intuition and judgement are required. However, it is not clear what job characteristics make a job suitable for automation. In addition, are there other important factors that need to be considered for automation and what are their impacts?

In this ERF paper, we propose a research framework for examining job automation. Two key contributing factors for job automation are *computerizability* and *consequence of error*. We perform a job-level analysis using the US O*NET database, which captures nearly 100 task characteristics for over 900 jobs. Our preliminary results support the framework and show that while job computerizability contributes positively to job automation, consequence of error has a curvilinear relationship with job automation.

Research Background

Prior studies have examined job automation from various perspectives. Researchers acknowledge significant difference exists in the levels of automation (LOA). For example, Sheridan and Verplank (1978) propose ten LOA involving decision making and actions, from the lowest level where humans must take all decisions and actions to the highest level where computers decide everything and act autonomously, ignoring the humans. As systems have both input and output, other researchers (Parasuraman et al. 2000; Parasuraman and Wickens 2008) propose an extension of LOA to a stage model that includes four information-processing stages: (*i*) information acquisition, (*ii*) information analysis, (*iii*) decision making, and (*iv*) action, with each stage having its own LOA scale.

However, most of these models focus on the functions, not the characteristics of jobs. A worker's job consists of many tasks, which are defined as activities that need to be conducted for certain work (Bystrom and Jarvelin 1995). Therefore, a better understanding about task characteristics can help determine which jobs are more suitable to be automated. One of the most important characteristics of a task is its complexity. Task complexity can be defined as the aggregation of any intrinsic task characteristics that influence the performance of a task (Liu and Li 2012).

Literature has suggested many task characteristics that are related to task complexity, such as variety, analyzability, determinability, uncertainty, novelty, dependencies, and the requirements on the number of inputs, coordination, cognitive and skill requirements, as well as the dynamic nature of task performance (Avgerinos and Gokpinar 2017; Bystrom and Jarvelin 1995; Campbell 1988; Liu and Li 2012; Wood 1986).

In a recent work, Frey and Osborne(2017) measure how likely it is for a job to be computerized, and, in doing so, they consider three dimensions that could influence job computerization: (*i*) perception and manipulation, (*ii*) creative intelligence, and (*iii*) social intelligence. They use the O*NET database and map O*NET task characteristics to these three dimensions to calculate the computerizability of jobs. However, the majority of the measurement items they use are not job-specific but are worker-related (such as finger dexterity, manual dexterity, originality, fine arts, social perceptiveness, negotiation, and persuasion). As have been noted, to conduct job analysis, the most important and appropriate information should be job or occupation-related (Blinder 2009), and all the dimensions we refer to in this research are as such.

Hypotheses Development

What makes a job more suitable for automation? Although various factors have been suggested, as reviewed above, we believe the decision to automate a job is primarily driven by two factors: the ease to automate and the consequence of automation. These two factors are analogous to the two factors in the well-known TAM model (Davis et al. 1989): perceived ease of use and perceive usefulness of a technology. Correspondingly, we propose a research framework of job automation, in which the two key contributing factors are *computerizability* and *consequence of error*. Our research framework is shown in Figure 1.

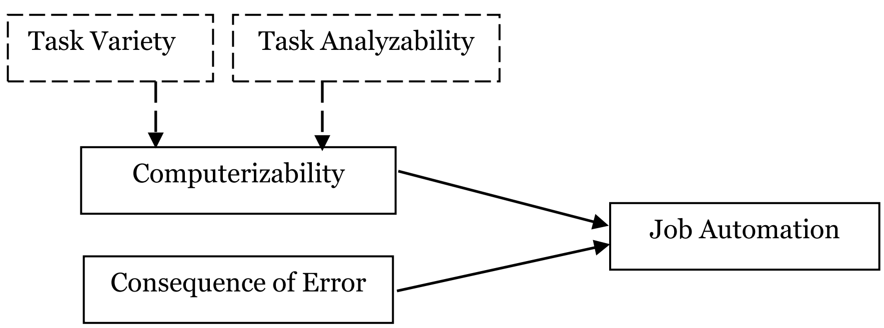

Figure 1. Research Framework

Computerizability

In our conceptualization, job *computerizability* measures the ease with which a job that a worker currently performs can potentially be programmed and delegated to computers or machines. Then how to measure job computerizability? For this, we take a cue from the seminal work of Perrow (1967), who proposed two important aspects of a task: (i) *variety*, and (ii) *analyzability*. Task variety refers to the frequency of exceptions or unexpected events that occur when performing a task. Task variety is low if few exceptions are encountered in carrying out the task and high if there are many variations and possibilities that can occur. With low task variety, the rules for perform the tasks can be clearly articulated and further translated into computer programs that designate what actions to take, in what sequences and under what contingencies. On the other hand, when task variety is high, many contingencies cannot be predicted, making the task difficult to be translated into logical instructions to computerize.

In contrast, task analyzability refers to the ease with which solutions can be searched and found when exceptions or unexpected events do arise. The higher the extent of search, the lower is the analyzability. High task analyzability suggests the existence of predetermined responses or well-defined procedures to perform the task; low task analyzability, on the other hand, suggests the solutions are often not well-defined, and human intuitions and judgment become necessary in performing the task.

Therefore, higher computerizability implies lower task variety and higher task analyzability. All else being equal, a job of higher computerizability is more likely to be automated when compared to one with lower computerizability. Thus, we have the following:

> **H1**: *Computerizability is positively associated with job automation.*

Consequence of Error

While computerizability represents the potential to automate a job, the decision to automate the job needs to take into consideration the consequence of automation, i.e., the cost and benefit of automation. Increased level of automation can bring about benefit through improved quality, accuracy, and precision for performing a task. However, automation can also incur significant cost, which can go far beyond development cost.

Computer is an accurate machine, and it can reduce man-made errors. Therefore, when quality, accuracy, and precision is important for performing a task, automation is a good solution. In these cases, automation can reduce errors, improve task accuracy and quality, make the product or service more reliable, and bring benefit to users. Today, automation is widely adopted in machine tools, assembly lines, and business processes, etc. Automation is also prevalent in everyday life such as navigation and aviation (Parasuraman and Wickens 2008).

However, automation can pose unpredictable problems and cause disasters for users. Poorly designed automation can increase workload and training requirements, decrease situation awareness, and, in extreme circumstances, lead to accidents due to errors in usage, material, or design (Miller and Parasuraman 2007; Onnasch et al. 2014; Parasuraman and Riley 1997). These errors can be rare, but once they do occur, the cost is enormous (Onnasch et al. 2014). The latest example is the recent crashes of two Boeing 737 Max planes due to malfunction of the maneuvering characteristics augmentation system (Wichter 2019). Therefore, when the stake or the consequence of error for performing a task is too high, such that the slightest error can cause immense disaster or cost, indiscriminate automation is not a good choice, and human intervention is required. Hence:

> **H2**: *Consequence of error has a curvilinear relationship with job automaton.*

Methodology and Results

To empirically test the hypotheses, we need to examine LOA of jobs as well as task characteristics related to computerizability and consequence of error. The US Occupational Information Network (O*NET) database turns out to be an ideal data source for this. The O*NET database is administered by the US Department of Labor, and it documents job-level information in the form of O*NET measurement items—or simply O*NET items—organized under six major categories. In this work, O*NET database is used to obtain task-level characteristics and is the basis for deriving the research variables—*level of automation*, *computerizability* and *consequence of errors*—for every job, based on its constituent tasks.

The O*NET Content Model, developed using research on job and organizational analysis, currently measures and stores a total of 261 measurement items under six different categories (O*NET 2015). Of these six categories, the only one that captures job characteristics is the category of "*Occupational Requirements*," which has 99 measurement items related to work activities, organizational context, and work context. The O*NET version 22, which we use for this study, stores scores on these 99 items for 964 occupations.

Prior literature suggests that LOA has many different levels. Therefore, we measure LOA as a continuous variable in this study. Specifically, our dependent variable, *level of job automation*, is measured by the O*NET item: "*How automated is the job*?"

To construct *computerizability*, we first identify the measurement items for its two constituent dimensions—*task variety* and *task analyzability*—as shown in Table 1.[1] We apply factor analysis on task variety and task analyzability, and the factor loadings for all items are all above 0.7, with Cronbach's α of 0.78 and 0.79. We then calculated *computerizability*=[(*1–task variety*)+*task analyzability*]/2.

Task Variety	**Task Analyzability**
Spend Time Making Repetitive Motions*	Judge the Qualities of Things, Services, or People*
Freedom to Make Decisions	Make Decisions and Solve Problems*
Structured versus Unstructured Work*	Think Creatively*

Table 1. O*NET Measurement Items

Finally, *consequence of error* is measured by the item: "*How serious would the result usually be if the worker made a mistake that was not readily correctable*?"

We apply ordinary least squares (OLS) model and conduct our analyses at job level with 964 observations. To verify if heteroscedasticity is present for our estimation, we conduct Breusch-Pagan test (Breusch and Pagan 1979). We reject the null that there is no heteroscedasticity in our data (χ^2 = 20.947 and $p<0.001$); therefore, we report the heteroscedasticity-robust standard errors in our results. The results are presented in Table 2, and they show that the coefficient on *computerizability* is positive and significant ($p<0.01$), and therefore H1 is supported. In addition, the coefficient on *consequence of error* is positive and significant ($p<0.01$), but that on the square of it is negative and significant ($p<0.01$), supporting H2 as well. In sum, the theoretical framework in Figure 1 is supported by our analyses.

Independent Variable	**Coefficient (s.d.)**
Computerizability	0.155*** (0.018)
Consequence of error	0.661*** (0.154)
Consequence of error^2	−0.429*** (0.124)
R^2	0.103

Notes: *N*=964; ****p*<0.01;

Table 2. Estimation Results

Discussions and Future Directions

We propose a research framework for job automation in this study. We empirically test the framework using the O*NET dataset. The results strongly support the framework, showing that job automation needs to consider its ease to automate and its consequence of error. This study makes several contributions. First, it proposes a parsimonious framework for job automation. Prior research has suggested a variety of factors that may affect the decision of automation, but we propose that the most relevant factors are computerizability and consequence of error, one representing the potential to automate and another the cost and benefit of automation. This could provide an anchor point for future studies. Second, it operationalizes computerizability through two dimensions: task variety and task analyzability, and further demonstrates how the two dimensions can be readily measured by existing O*NET database items. Third, it argues and confirms that the consequence of error for automation has a curvilinear relationship with

[1] Note: Items with an asterisk (*) are reverse-coded.

job automation. Below certain threshold, the higher the level of consequence of error, the more the need for automation, since the benefit of automation outweigh its cost. However, once the level of consequence of error has passed certain threshold, automation becomes less desirable due to the unbearable cost that may occur; in this case, human intervention becomes indispensable. Forth, the theoretical framework can be used to predict what jobs are suitable for automation and to what extent they can potentially be automated. These propositions and findings are interesting and novel and contribute to current research and practice on job automation. Although the research context is automation in this study, we believe the framework can be applied to artificial intelligence as well.

There are a few planned research directions. Our theoretical framework needs to be further enriched. For example, other factors such as trust toward automation, work environment, and task modularity can also influence automation and we plan to incorporate them. Mediating or moderating factors may exist and thus deserve further investigation. Longitudinal study of job content change is also planned for. These future directions will shed more light on this important and fast-growing research topic.

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