Definition and Verification of Workers’ Aptitude Toward Assembly Tasks in Production Cells

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Abstract: Major studies on cell production have put the emphasis on technical factors (machine order/layout, family part grouping, workflow sequence, etc.), it is still insufficient to investigate how workers’ aptitude affect the productivity of production cells. As the first attempt to examine the workers’ aptitude toward the assembly tasks in production cells, we make a comparatively detailed literature review on the major theories and assessment measures developed in the field of industrial and organizational psychology. Then we give the definition of four aptitudes and related hypotheses from the aspects of workers’ cognition and interest, finger dexterity, affection, and behavioral intention. We design a self-evaluation sheet to measure the workers’ aptitudes, and moreover design a cell production experiment to investigate the relation between the workers’ aptitudes and productivity of production cells. Through our experimental study, we verified statistically that the workers’ cognition and interest, negative affection correlate significantly to the productivity of production cells. However, there are still some issues to be addressed further in order to measure the workers’ aptitudes through the self-evaluation sheet.

Key Words: Cell Production, Cellular Manufacturing, Experimental Study, Workers’ Aptitude

1. Introduction

With the obvious trend of economic globalization and intense competition, industry manufacturing systems have to quickly correspond to various and quantitative market requirements. There has been an increase in demand in industry for cellular manufacturing systems or cell production systems in order to improve productivity and process flexibility. The cell production has become an integral part of lean manufacturing systems; many organizations have applied cell production concepts in manufacturing and service processes. Some of the reported benefits of cell production are reduced setup times, reduced in-process inventories, improved product quality, shorter lead times, reduced tool requirements, improved productivity, and better overall control of operations. Furthermore, implementation of cell production has been shown to achieve significant improvements in space utilization and employee morale [1].

Cell production systems have gained significant research attentions. Over the past 30 years, numerous techniques and methods have been developed that focused mainly on technical aspects of cell production, such as the best groupings for products, parts, or machine clusters. Some researchers have considered selecting tools, jigs, and fixtures, determining process flow, determining cell capacity and selection of equipment. However, as some researchers have reported, for successful implementation of production cells, people who will eventually operate, manage, support and maintain the production cells should actively participate in their design and development [2],[3]. Wemmerlov & Johnson [4] surveyed 46 user plants with 126 cells and concluded that substantial benefits could be achieved from cellular manufacturing but that implementation is not simply a rearrangement of the factory layout; it is a complex reorganization that involves organizational and human aspects. They emphasized that most of the problems faced by companies implementing cells were related to people, not technical issues.

In our previous studies [5],[6], we have shown that both the experience (learning effect) and workers have significant impacts on the productivity of production cells, the impact of the experience and workers on the productivity of production cells account for 19.63% and 67.01% of the total variance in assembly times respectively. As two-thirds of variance of the assembly times were decided by workers, the aptitude or ability of workers has a stronger impact than the experience. In order to implement cell production systems successfully, it is very important to measure workers’ aptitude and assign the right workers in the right place.

Although the workers’ aptitude is the key to successful implementation of production cells, there is a singular absence of articles of investigating the impact of workers’ aptitude on production cells because human-related issues are typically difficult to quantify [7]. As the vast majority of cell production literature considers manufacturing cells only from technical aspect, these researches only consider human workers as workers assignment strategy in terms of their labor capacity, or rate at which they can produce a part, and not in terms of the skills
or aptitude they possess. It remains an issue how to identify or define the workers’ aptitude for production cells, and it is necessary to develop an effective approach for measuring workers’ aptitude.

In this paper, we define and verify the workers’ aptitude toward assembly tasks in production cells. We put our emphasis on how to recognize significantly valid aptitudes of the workers through experimental study method, and make the following contributions:

(1) In the field of industrial and organizational psychology (I-O psychology), many studies have been made to identify individual difference, a lot of theory such as the Five-Factor Model (FFM) and Cattell-Horn-Carroll (CHC) theory have been proposed and applied widely. However, according person-job-fit theory, different jobs require workers with slightly different characteristics for fitting in and performing optimally. It is yet not clear what abilities of workers are important for successful implementation of production cells. This paper give the definition of four aptitudes and related hypotheses for cell production from the aspects of workers’ cognition and interest, finger dexterity, affection and behavioral intention. Then we confirm their validity. To our knowledge, this study is the first attempt to consider the four workers’ aptitudes toward the assembly tasks in production cells.

(2) Although some researchers have considered the impact of aptitudes or abilities of workers on the performance of production cells, all most of previous researches applied questionnaire survey or case study methods. Due to the limit of these methods, it is only possible to evaluate the impact of the workers’ aptitude comparatively and empirically. Different from previous researches, this paper will apply the experimental study method to clarify the relationship between the workers’ aptitude and productivity of production cells quantitatively.

(3) We design a self-evaluation sheet to measure the workers’ aptitude toward the assembly tasks in production cells and apply the regression analysis method to examine the validity of the workers’ aptitude measurement that was extracted from the self-evaluation sheet. Through these results, we verify the hypotheses on the defined aptitudes and clarify the issues for measuring workers’ aptitude.

The remainder of this paper is organized as follows. As the basic starting point, we give a comparatively detailed literature review on the major theories and assessment measures developed in the field of industrial and organizational psychology at next section. Then we give the definition of four aptitudes and related hypotheses in section 3. The design of the self-evaluation sheet for measuring the workers’ aptitude, and the design of the cell production experiment are described in section 4 and section 5 respectively. At section 6, we conduct a principal component analysis to extract worker aptitudes and then conduct a regression analysis to verify statistically the validity of the workers’ aptitudes. At last, we summary this paper and give some concluding remarks.

2. Literature Review

2.1 Individual Differences

Many organizations such as universities and companies need comprehensive, reliable and valid tools to assess the ability of thousands of applicants in order to select the most capable students or employees. Respondent to this social need, researchers in the field of industrial and organizational psychology have long been interest in measuring and charting the differences among people using "psychological" variables. Adults have a variety of attributes (e.g., intelligence, personality, interests) and the levels of these attributes are relatively stable over a reasonable time period (several years). Scientists refer to the ways in which people differ from one another as individual differences. Individual differences can have major influences on people’s thinking and behavior as well as people’s job success, lives and careers. There is a growing consensus that there are many different attributes of people that serve many different demands of the job, as shown in Figure 1. We can divide the individual differences useful in understanding work behavior into the following categories:

- Cognitive ability
- Physical ability
- Personality
- Values
- Interests
- Knowledge
- Skill
- Experience and Emotion

Fig. 1 The Link between Individual Difference and Behavior in Organizations

(1) Cognitive ability: refers to capacity to reason, plan, and solve problems; scientists often use mental ability as the synonym of cognitive ability.

(2) Physical ability: refers to people’s capacities to engage in the physical tasks required to perform a job. There are several types of physical ability that are relevant to a wide variety of jobs. These include strength (the capacity to exert physical force against various objects), flexibility (the capacity to move one’s body in an agile manner), stamina (the capacity to endure physical activity over prolonged periods) and speed (the ability to move quickly).

(3) Personality: refer to an individual’s habitual way of responding or an individual’s behavioral and emotional characteristics. Personality was generally found to be stable over time and in a variety of circumstances.

(4) Values: refer to stable life goals that people have, reflecting what is most important to them. Values are established throughout one’s life as a result of the accumulating life experiences and tend to be relatively stable. The values...
that are important to people tend to affect the types of decisions they make, and their actual behaviors. People are more likely to accept job offers when the company possesses the values people care about.

(5) Interests: preferences or likings for broad ranges of activities. According to the model developed and presented by Holland [11], there are six interest types of people: Realistic, Investigative, Artistic, Social, Enterprising, and Conventional; it is known by the acronym, RIASEC.

(6) Knowledge: a collection of specific and interrelated facts and information about a particular topical area. It is acquired through formal education or training, or accumulated through specific experiences. The researchers distinguish knowledge into tacit knowledge (procedural knowledge) and formal or academic knowledge (declarative knowledge). Tacit knowledge refers to action-oriented, goal-directed knowledge (knowing how), while academic knowledge may not be always goal-directed and is just one of knowing that.

(7) Skill: refers to practiced acts, such as shooting a basketball, using a computer keyboard, or persuading someone to buy something. Technical and job-related skills are as varied as jobs and job tasks. Skills can be developed through practice without certain cognitive or physical abilities and personality characteristics, and knowledge.

(8) Emotion: refers to an affect or feeling, often experienced and displayed in reaction to an event or thought and accompanied by physiological changes in various systems of the body. Emotional intelligence is a new kind of ability to understand and manage one’s own feelings and emotions and the feelings and emotions of others. Emotional Intelligence also helps promote effective functioning and well-being among employees [12].

2.2 Cognitive Ability

The Cattell-Horn-Carroll (CHC) theory of intelligence is the most comprehensive and empirically supported psychometric theory of the structure of cognitive abilities to date. It is a synthesis of Cattell and Horn’s Gf-Gc model of fluid and crystallized intelligence, and Carroll’s Three Stratum Hierarchy. CHC model locates cognitive abilities into three structural levels [13]. On top of the CHC hierarchy is the g (global or general ability). The first generation of CHC theory includes 10 broad cognitive abilities on the middle level. The broad abilities are considered too broad to be represented by any single measure, thus there are over 70 narrow abilities on the ground level. In the late 1990s, McGrew proposed a number of extensions to CHC theory. The latest refinements to CHC theory are detailed in the works of Schneider and McGrew [14],[15]. In this model, CHC theory includes 16 broad cognitive abilities, which are subsumed by over 80 narrow abilities.

The broad abilities are:[15]

(1) Fluid Intelligence (Gf): refers to mental operations that an individual uses when faced with a relatively novel task that cannot be performed automatically. These mental operations may include forming and recognizing concepts, perceiving relationships among patterns, drawing inferences, comprehending implications, problem solving, extrapolating, and reorganizing or transforming information.

(2) Crystallized Intelligence (Gc): refers to the breadth and depth of a person’s acquired knowledge and skills that are valued by one’s culture. Gc includes both declarative (static) and procedural (dynamic) knowledge. Declarative knowledge includes factual information, comprehension, concepts, rules, and relationships, especially when the information is verbal in nature. Procedural knowledge refers to the process of reasoning with previously learned procedures in order to transform knowledge.

(3) General (domain-specific) Knowledge (Gkn): is the depth, breadth, and mastery of specialized knowledge (knowledge not all members of a society are expected to have).

(4) Quantitative A New Kind of Ability (Gq): represents an individual’s depth and breadth of knowledge related to mathematics. It is the ability to comprehend quantitative concepts and relationships and to manipulate numerical symbols.

(5) Reading and Writing Ability (Grw): includes both basic abilities (e.g., reading decoding and fluency, spelling) and complex abilities (e.g., comprehending written discourse, writing a story).

(6) Short-Term Memory (Gsm): is the ability to apprehend and hold information in immediate awareness and then use it within a few seconds.

(7) Long-Term Storage and Retrieval (Glr): is the ability to store information in and fluently retrieve new or previously acquired information (e.g., concepts, ideas, items, names) from long-term-memory.

(8) Visual Processing (Gv): is the ability to generate, perceive, analyze, synthesize, store, retrieve, manipulate, transform, and think with visual patterns and stimuli.

(9) Auditory Processing (Ga): is the ability to analyze, synthesize, and discriminate auditory stimuli, including the ability to process and discriminate speech sounds that may be presented under distorted conditions.

(10) Olfactory Abilities (Go): refer to the abilities to detect and process meaningful information in odors. This broad ability does not account for how sensitive one is to smell, but rather the cognitive processes an individual uses to interpret information from the olfactory system.

(11) Tactile Abilities (Gh): is the abilities to detect and process meaningful information in haptic (touch) sensations.

(12) Psychomotor Abilities (Gp): refer to the abilities to perform physical body motor movements (e.g., movement of fingers, hands, legs) with precision, coordination, or strength.

(13) Kinesthetic Abilities (Gk): is the abilities to detect and process meaningful information in proprioceptive sensations.
(14) Processing Speed (Gs): is the ability to perform automatic cognitive tasks, particularly when measured under pressure to maintain focused attention.

(15) Decision Speed/Reaction Time (Gt): reflects an individual’s quickness in reacting (reaction time) and making decisions (decision speed). Gt is also considered as the speed of making very simple decisions or judgments when items are presented one at a time.

(16) Psychomotor Speed (Gps): is the speed and fluidity with which physical body movements can be made.

There are many literatures showing that intelligence is a good predictor of both job performance and training proficiency at work. Extensive meta-analytic reviews have shown that intelligence was a good predictor of job performance but particularly in complex jobs. Since this model accommodated both theoretical cognitive constructs and empirical findings, no single measurement nowadays covers all CHC abilities, and extension of the construct is still an ongoing action.

2.3 Personality

The Big Five or the Five-Factor Model (FFM) of personality is the most current, valid and reliable personality lens framework available today. It has been widely accepted by most researchers as universally generalizable model in the area of personality structure. Psychologists use it as the primary means for understanding and interpreting personality.

According to this model, there are five factors that are usually measured in percentages and under each of the factors, various other sub-factors are included such as gregariousness, assertiveness, excitement seeking, warmth, activity, and positive emotions under extroversion.

The five factors are as follows[16].

(1) Neuroticism: refers to the tendency to experience negative emotions such as anxiety, anger, or depression. Neuroticism also refers to the degree of emotional stability and impulse control, and is sometimes referred to by its low pole, emotional stability. A high need for stability (low in neuroticism) manifests as a stable and calm personality, but can be seen as uninspiring and uninterested. A low need for stability (high in neuroticism) causes a reactive and excitable personality, often very dynamic individuals, but they can be perceived as unstable or insecure. They respond emotionally to events that would not affect most people, and their reactions tend to be more intense than normal. They are more likely to interpret ordinary situations as threatening, and minor frustrations as hopelessly difficult. Their negative emotional reactions tend to persist for unusually long periods of time, which means they are often in a bad mood.

(2) Extroversion: refers to high activity, assertiveness, and a tendency towards social behavior. Extroverts enjoy being with people, are full of energy, and often experience positive emotions. They tend to be enthusiastic, action-oriented, individuals who are likely to say “Yes!” or “Let’s go!” to opportunities for excitement. In groups they like to talk, assert themselves, and draw attention to themselves. Introverts lack the exuberance, energy, and activity levels of extroverts. They tend to be quiet, low-key, deliberate, and disengaged from the social world. Their lack of social involvement should not be interpreted as shyness or depression; the introvert simply needs less stimulation than an extrovert and prefers to be alone.

(3) Openness to Experience: reflects the degree of intellectual curiosity, creativity and a preference for novelty and variety a person has. Openness is considered to be positive; the basic understanding was ‘the more open the person is, the more the potential for intellectual curiosity, creativity, appreciation of art and sensitivity to beauty.’ It is also an indication of how imaginative and independent the individual is. People who score high on openness prefer a multitude of activities over a daily schedule with the same activities. High openness can be perceived as unpredictability or lack of focus. People with low scores on openness to experience tend to have narrow, common interests. They prefer the plain, straightforward, and obvious over the complex, ambiguous, and subtle. They may regard the arts and sciences with suspicion, regarding these endeavors as abstract or of no practical use. Closed people prefer familiarity over novelty; they are conservative and resistant to change.

(4) Agreeableness: Agreeableness or sociability reflects individual differences in concern with cooperation and social harmony. Agreeable individuals value getting along with others. They are therefore considerate, friendly, generous, helpful, and willing to compromise their interests with others. Agreeable people also have an optimistic view of human nature. They believe people are basically honest, decent, and trustworthy. Disagreeable individuals place self-interest above getting along with others. They are generally unconcerned with others’ well-being, and therefore are unlikely to extend themselves for other people. Sometimes their skepticism about others’ motives causes them to be suspicious, unfriendly, and uncooperative.

(5) Conscientiousness: is associated with efficiency, determination, responsibility, and persistence. This includes how individuals control, regulate, and direct their impulses. Impulses are not inherently bad; occasionally time constraints require a snap decision, and acting on our first impulse can be an effective response. Also, in times of play rather than work, acting spontaneously and impulsively can be fun. Impulsive individuals can be seen by others as colorful, fun-to-be-with, and zany. Conscientiousness includes the factor known as Need for Achievement (N Ach). Conscientious individuals avoid trouble and achieve high levels of success through purposeful planning and persistence. They are also positively regarded by others as intelligent and reliable. On the negative side, they can be compulsive perfectionists and workaholics. Furthermore, extremely conscientious individuals might be regarded as stuffy and boring. Unconscious people may be criticized for their unreliability, lack of ambition, and failure to stay within the lines, but they will experience many short-lived pleasures and they will never be called stuffy.

From the mid-1980s to the mid-1990s, the Five-Factor Model of personality was tested in academic and research communi-
ties worldwide and was found to be a superior model to earlier means of explaining and describing personality. There have been dozens of studies that have demonstrated that the Big Five traits are related to various aspects of job performance. Personality assessment measures based upon the Big Five factors of personality, can effectively predict job performance and thus can be used for personnel selection[17].

On the other hand, there are also some criticism about this model. The main criticism is that it fails to explain the whole of human personality. The factors are said to not independent of each other and hence, affect each other. Methodologically, there is no universally accepted mechanism to measure the factors. Theoretically, the model is not based on any profound theory. It is merely an empirical activity.

### 2.4 General Aptitude Test Battery

The General Aptitude Test Battery (GATB) is a work-related multiple-ability assessment developed by the U.S. Employment Service (USES), a division of the Department of Labor. GATB edition B-1002 comprised 12 tests and was published in 1947 in two forms (A and B). Two additional forms (C and D) were subsequently published in 1983. U.S. State employment service offices used the GATB for vocational counseling and applicant referral. High schools, technical schools, universities, and other authorized agencies used the battery for vocational and career counseling [17],[18].

In the late 1980s, a review of the GATB by the U.S. National Research Council (NRC) of the National Academy of Sciences raised a number of concerns, and subsequently, the battery went through several important changes in development. The result of the revision process comprised GATB Forms E and F, now referred to as Ability Profiler Forms 1 and 2 respectively. Students and workers may use the Ability Profiler to identify their strengths and occupations associated with those strengths. The profiler also helps individuals identify areas in which they might want more training and education.

The current GATB or Ability Profiler, comprising 11 separately timed tests, measures nine work-related abilities:[17]

1. **Verbal Ability**: ability to understand the meaning of words and use them effectively in good communication when you listen, speak, or write.
2. **Arithmetic Reasoning**: ability to use several math skills and logical thinking to solve problems in everyday situations.
3. **Computation**: ability to use arithmetic operations of addition, subtraction, multiplication, and division to solve everyday problems involving numbers.
4. **Spatial Ability**: ability to form pictures of objects in testers’ mind.
5. **Form Perception**: ability to quickly and accurately see details in objects, pictures, or drawings.
6. **Clerical Perception**: ability to quickly and accurately see differences in detail in printed material.
7. **Motor Coordination**: ability to quickly and accurately coordinate eyes with hands or fingers when making precise hand movements.
8. **Manual Dexterity**: ability to quickly and accurately move hands easily and skillfully.
9. **Finger Dexterity**: ability to move fingers skillfully and easily.

Numerous studies indicate the GATB instruments demonstrate acceptable test-retest reliability (most estimates are greater than .70), convergent validity. Hundreds of predictive validity studies have been performed on data sets incorporating GATB scores, usually correlated with one or more job performance measures, such as supervisor ratings, output-per-time period, promotions, earnings increases, and so on. Although extensive research generally supports the reliability and validity of earlier GATB forms, some researchers insist that the GATB was developed only for career exploration, career counseling, but not for job selection or selection into job [19].

### 3. Workers’ Aptitude to Production Cell

#### 3.1 Definition and Hypothesis

Job performance of workers plays a crucial factor in determining performance of cell production system. Highly performing individuals will be able to assist companies to achieve higher productivity thus sustaining the companies’ competitive advantage. In the field of industrial-organizational psychology, the person-job fit theory has been proposed [20]. This is the concept that recognizes the requirements of the job moderated by the relationship between possession of the personality characteristic and job performance or in other words matching the job requirements with personality characteristics.

Person-job fit can be classified into demand-abilities perspective and needs-supplies perspective. According to the demand-abilities perspective, the fit of demand-abilities could be achieved when individuals bring sufficient knowledge, skill and abilities (KSAs) to meet the job demand. The closer the traits between the person and the job match, the higher the chance of workplace productivity. The needs-supplies fit exists when the supplies offered from jobs are compatible to the needs, preferences and desires of individuals. Hence, the best personality fit will decrease job turnover and stress, absenteeism, and poor job satisfaction.

According to the person-job fit theory, we can define the workers’ aptitude toward the assembly tasks in production cells as the potential ability of workers to perform the tasks, which generally consists of a combination of workers’ cognitive abilities, personality, physical abilities, interests and skills. Because the aptitude is the compatibility between workers abilities and the job or tasks characteristics, we can consider the necessary abilities based on characteristics of the assembly tasks in production cells. Here, we define the following four aptitudes and give the hypotheses on the relation between these aptitudes and performance of production cells.

1. **Finger Dexterity**: finger dexterity or fine motor skill covers the ability to grasp and hold objects, and to perform fine finger movements to manipulate small objects. In production cells, the workers usually assemble some products that consists of many small parts. These assembly tasks require physical manipulation of controls and manual handling. Finger dexterity is the key to many assembly tasks
in production cells. Therefore, the following hypothesis is proposed in the study.  
H1: Workers’ finger dexterity will positively relate to productivity of production cells.

(2) Cognition and Interest: this refers to the thoughts, beliefs, and ideas the workers have about the assembly tasks. If workers have deep cognition on the significance of assembly tasks or they are interested in doing these tasks, they will do their best in production cells. As the result, it is conducive to improve productivity. Based on this consideration, the following hypothesis is proposed in the study.  
H2: Workers’ cognition and interest on the assembly tasks will positively relate to productivity of production cells.

(3) Behavioral intention: refers to tendency or disposition to act in certain ways toward the assembly tasks in production cells. Although what we intend and what we do may be quite different, high intention of doing the assembly tasks leads directly to strong desire to do the tasks and gives positive influences on productivity. In contrast, if a worker has no intention of doing the assembly tasks the worker will not be willing or will be lack of motivation to work hard. Therefore, the following hypothesis is proposed in the study.  
H3: Workers’ behavioral intention will influence performance of production cells.

(4) Affection: refers to the emotional reaction or the feeling the workers have toward the assembly tasks in production cells. If the workers feel that the assembly tasks are enjoyable or pleasurable, they are satisfied with the tasks and in turn this leads to higher productivity. In contrast, when the workers felt that the tasks are very troublesome, they may not enjoy doing these tasks and this leads to low performance. According to this consideration the following hypothesis is proposed in the study.  
H4: Workers’ affection will influence performance of production cells.

There are also some aptitudes such as learning ability, endurance that have large influences on the productivity of production cells, we are going to investigate these factors as another study and no longer consider them here.

3.2 Self-Evaluation Sheet Design  
In order to measure the workers’ aptitudes defined in the previous subsection, we designed a self-evaluation sheet, as showed in Table 1. The self-evaluation sheet consists of 11 items and the workers are required to answer these self-evaluation items before starting the assembly tasks. When answering the self-evaluation sheet, a five-point Likert scale was applied.

| No | Evaluation Item                                                                 |
|----|--------------------------------------------------------------------------------|
| Q1 | I’m interested in this experiment                                               |
| Q2 | This experiment seems to be fun                                                 |
| Q3 | This experiment seems difficult                                                 |
| Q4 | I think this experiment is significant for me                                  |
| Q5 | This experiment is quite troublesome                                           |
| Q6 | I like experimental subjects including this experiment                         |
| Q7 | I like making something                                                          |
| Q8 | I am going to actively participate in this experiment                          |
| Q9 | I like the classroom lectures better than experiments                           |
| Q10| Fine work is my favorite                                                        |
| Q11| My fingers are dexterous                                                         |

3.3 Cell Production Experiment Design  
We designed a laboratory experiment to test the hypotheses built at the previous section. The virtual good is the toy robot that built up of the LEGO Mindstorms (see Fig.2), which consists of 106 pieces of parts and the assembling process is divided into 17 tasks. The performance of production cells is evaluated by the assembly time required to complete a toy robot. Considering more non-permanent employees work in the shop floor of cell production systems, we designed the experiment on the assumption that the workers have no any experience of assembling the toy robot.

The experiment is carried out along with the following steps:

1. Step 1: At first, we give the workers some assembly manuals and then, a instructor demonstrates the assembly tasks of the toy robot through assembling it practically in front of the workers. Following the instructor’s demonstration, the workers learn the sequence and techniques to assemble the toy robot, and then assemble one toy robot by one-self.

2. Step 2: After the instruction, the workers assemble the toy robot in the mode of one-person cell. When doing the assembly tasks, the workers measure the operation time needed to complete every task but the disassembling operation time is not included. Furthermore, the workers have not been given a standard time for the assembly tasks.

3. Step 3: The assembly time required to assemble a toy robot is calculated as the sum of operation times of all tasks. In order to investigate the learning effect, the assembly and time measurement are repeated five times.

5. Experiment Result  
5.1 Basic Statistics of Assembly Times  
We conducted the experiment during the period from October 2013 to January 2014. As the workers, there are 60 students in Fukushima university participated the experiment. 55 of them
could complete the assembly and time measurement five times, and returned valid answers to the self-evaluation sheet. Basic statistics of the assembly times for all of one person cell are shown in Table 2, where the experience represents the order of the assembly and time measurement.

| Statistics | Experience |
|------------|------------|
|            | 1st | 2nd | 3rd | 4th | 5th |
| Mean       | 10.74 | 8.59 | 7.77 | 7.21 | 6.64 |
| Std. deviation | 2.91 | 2.18 | 2.09 | 2.96 | 1.64 |
| Minimum    | 6.23 | 5.43 | 4.67 | 4.33 | 3.90 |
| Maximum    | 19.63 | 15.18 | 14.52 | 14.02 | 12.33 |
| Range      | 13.40 | 9.75 | 9.85 | 9.68 | 8.43 |

From Table 2, it is clear that the average time required to assemble a toy robot at the first experience was 10.74min and it got shorter into 6.64min at the fifth experience. As the assembly times decreased along with increasing of the workers’ experience, learning effect could be confirmed statistically. The range of the assembly times is from 13.40min to 8.43min and there is a difference more than three times between the slowest worker and the fastest one. Therefore workers’ aptitude gives a strong impact to performance of production cells.

5.2 Results of Self-Evaluation

The answers of self-evaluation from 55 workers were collected and the boxplot of the self-evaluation result is showed in Fig.3. There are four items: Q1 (I’m interested in this experiment), Q2 (This experiment seems to be fun), Q7 (I like making something) and Q8 (I am going to actively participate in this experiment) that the workers gave higher points of self-evaluation. The third component PC3 and the fourth component PC4 account for 13.3% and 9.9% of the total variance respectively. Moreover, the overall KMO (the Kaiser-Meyer-Olkin Measure of Sampling Adequacy for the overall dataset) is 0.698 and the p-value of Bartlett’s test of sphericity is 0.0%, the PCA result of Table 3 is admissible.

Table 4 shows the PCA structure matrix, where large coefficient (the absolute value >0.50) for each variable to every component are highlighted in bold. As structure matrix represents the correlations between the variables and the principal components, we can interpret the principal components according to these correlation coefficients.

1. The first principal component (PC1): PC1 correlates strongly Q1 (I’m interested in this experiment), Q8 (I am going to actively participate in this experiment) and Q4 (I think this experiment is significant for me). It also negatively correlates to Q3 (This experiment seems difficult). As these items aim at knowing the workers’ thoughts and ideas about the assembly tasks, PC1 gives a measure for the workers’ cognition and interest about the tasks. Based on this consideration, we name PC1 the workers’ cognition and interest.

2. The second principal component (PC2): PC2 positively correlates to Q10 (Fine work is my favorite) and Q11 (My fingers are dexterous). As these two items is to know the workers’ finger dexterity, we simply name PC2 the measure of finger dexterity.

3. The third principal component (PC3): PC3 correlates positively to Q6 (I like experimental subjects including this experiment) and Q7 (I like making something), and it also negatively correlates to Q9 (I like the classroom lectures better than experiments). These items represent if the works have the intention of doing the assembly tasks, we name PC3 the measure of the workers’ behavioral intention.

4. The fourth principal component (PC4): PC4 correlates positively with Q5 (This experiment is quite troublesome) and negatively with Q2 (This experiment seems to be fun). These two items indicate how the workers feel negatively about the assembly tasks, it is natural to name PC4 the measure of the workers’ negative affection.

6. Hypotheses Verification

6.1 Aptitude Extraction

Based on the answers of self-evaluation sheet from 55 workers, we conducted the Principal Components Analysis (PCA) to extract the aptitude of the workers. We used IBM SPSS Statistics 20.0 and applied the eigenvalue-one criterion to decide the number of meaningful components. We also used Promax with Kaiser Normalization as the rotation method to identify the final principal components. We obtained the PCA result as shown in Table 3.

According to Table 3, we could extract four principal components; these components explain together 75.1% of the global data dispersion. The first principal component (PC1) accounts for 34.9%, and the second principal component (PC2) accounts for 17.0% of the variance of the answers to the 11 self-evaluation items. The third component PC3 and the fourth component PC4 account for 13.3% and 9.9% of the total variance respectively. Moreover, the overall KMO (the Kaiser-Meyer-Olkin Measure of Sampling Adequacy for the overall dataset) is 0.698 and the p-value of Bartlett’s test of sphericity is 0.0%, the PCA result of Table 3 is admissible.

6.2 Regression Analysis and Hypothesis Verification

As described above, we could extract four principal components from the answers to the self-evaluation sheet, and the four component scores for each worker are exactly the evaluation values of the worker’s four aptitudes. Here, we denote the jth principal component score of the ith worker as sj, (i = 1, 2, · · · , 55; j = 1, 2, 3, 4). To investigate how these workers’ aptitude affect the performance of production cells, we also...
used IBM SPSS Statistics 20.0 and conducted a regression analysis where the independent variables are the evaluation values of the worker’s four aptitudes, $s_{ij}$, the dependent variable is the assembly time $t_{5i}$ for the $i$th worker required at the fifth experience.

Table 5 Result of Regression Analysis

| Variable | Component | Standardized Regression Coefficient | t-value | p-value |
|----------|-----------|--------------------------------------|---------|---------|
| PC1 ($s_{i1}$) | -0.290 | 2.005 | 0.050 |
| PC2 ($s_{i2}$) | 0.090 | 0.671 | 0.505 |
| PC3 ($s_{i3}$) | -0.037 | -0.245 | 0.807 |
| PC4 ($s_{i4}$) | 0.229 | 1.749 | 0.086 |

Table 5 shows the standardized regression coefficients and their $p$-values. From Table 5, it is clear that:

(1) As the standardized regression coefficient for PC1 scores is -0.290 and the $p$-value is 5.0%, PC1 scores have significantly negative correlation to the assembly times. This means that the workers’ cognition and interest positively correlates to the productivity of production cells. According to this result, hypothesis H2 could be confirmed significantly.

(2) Because the $p$-values for PC2 scores and PC3 scores are 50.5% and 80.7% respectively, the correlations between assembly times and PC2 scores (finger dexterity), as well as assembly times and PC3 scores (behavioral intention) could not verified statistically. Therefore, we could not verify if hypotheses H1 and H3 are true.

(3) The standardized regression coefficient for PC4 scores is 0.229 and the $p$-value is 8.6%. Although the $p$-value is a bit high there is no big problem to consider that PC4 scores positively correlate to the assembly times. That is, the workers’ negative affection leads to increase of assembly times, and therefore it negatively correlates to the productivity of production cells. According to this result, hypothesis H4 could be verified statistically.

6.3 Discussion and Issues

Although we could extract four aptitudes from the answers to the self-evaluation sheet, but we could verify only two of them having significant relation to productivity of production cells. This result is very different from our expectation that in particular, the workers’ finger dexterity should have a strong impact on the performance of production cells. Fig. 4 shows the boxplot of assembly time $t_5$ at the fifth experience grouped by answers to Q11 (My fingers are dexterous).

From Fig. 4, it is obvious that the median of assembly time $t_5$ varies irregularly with the answer to Q11. As the assembly time $t_5$ of the workers who answered 5 (Strongly agree) to Q11 scattered widely, some workers over-evaluated themselves even if they took longer time for the assembly tasks. Meanwhile, although some workers could complete the assembly in a very short time, they under-evaluated themselves and answered 1 (Strongly disagree) or 2 (Disagree) to Q11. These results suggest that the workers have not an uneven standard to evaluate their finger dexterity.

Because some workers are likely to under-evaluate themselves and on the other hand, some of them prefer to over-evaluate. It is also possible to apply some existing methods to limit the effects of faking.

Because some workers are likely to under-evaluate themselves and on the other hand, some of them prefer to over-evaluate themselves. There is the effectiveness barrier to be overcome in order for us to apply the self-evaluation sheet to measure the workers’ aptitudes. The following two issues should be addressed further:

(1) Recognizing and correcting under/over evaluation: It is necessary to recognize under/over evaluation answers and correct them properly. Psychological principles seems to be applicable to recognize workers’ personality of under/over evaluation. It is also possible to apply some existing methods to limit the effects of faking.

(2) Development of deeper structure: as the relation between workers’ aptitudes and job performance is very complex, there is a possibility that it is not appropriate to consider this relation be linear. It is necessary to find deeper structure about the influence of workers’ aptitudes on perfor-
formance of production cells. For example, it may be possible to find non-linear relations between workers’ aptitudes and performance of production cells. It is also desirable to introduce control variables or moderating/mediating variables and develop more complex structure.

7. Concluding Remarks

This paper is our first attempt to examine the workers’ aptitude toward the assembly tasks in production cells, the main results can be summarized as the following:

- We gave the definition of four aptitudes and related hypotheses from the aspects of workers’ cognition and interest, finger dexterity, affection, and behavioral intention.

- We designed a self-evaluation sheet to measure the workers’ aptitude. According to the result of principal component analysis based on the answers to the self-evaluation sheet, we could extract four principal components that exactly represent the workers’ four aptitudes.

- Based on the assembly time measured at the cell production experiment, we examined the relation between the workers’ aptitudes and productivity of production cells. According to the result of regression analysis, it could be verified that the workers’ cognition and interest, negative affection correlate significantly to the performance of production cells.

- Because workers’ cognition and interest, finger dexterity could not be verified to have significant relation with the performance of production cells. There are still some issues to be addressed further in order to measure the workers’ aptitude through the self-evaluation sheet.

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References

[1] Liu, C., Lian, J., Yin, Y., & Li, W. (2010). Seru Seisan— an innovation of the production management Mode in Japan. Asian Journal of Technology Innovation, 18(2), 89-113.

[2] Olorunniwo, F. O., & Udo, G. J. (1996). Cell design practices in US manufacturing firms. Production and Inventory Management Journal, 37(3), 27.

[3] Yauch, C. A., & Steudel, H. J. (2002). Cellular manufacturing for small businesses: key cultural factors that impact the conversion process. Journal of operations management, 20(5), 593-617.

[4] Wenmerlov, U., & Johnson, D. J. (1997). Cellular manufacturing at 46 user plants: implementation experiences and performance improvements. International journal of production research, 35(1), 29-49.

[5] Hao, X., Haraguchi, H., & Dong, Y. (2013). An Experimental Study of Human Factors’ Impact in Cellular Manufacturing and Production Line System. Information, 16(7A), 4509-4526.

[6] Dong, Y., Haraguchi, H., & Hao, X. (2014). Structural Equation Modelling of Human Factors and Their Impact On Productivity of Cellular Manufacturing. Innovation and Supply Chain Management, 8(1), 1-7.

[7] Bidanda, B., Ariyawongrat, P., Needy, K. L., Norman, B. A., & Tharmmapornphilas, W. (2005). Human related issues in manufacturing cell design, implementation, and operation: a review and survey. Computers & Industrial Engineering, 48(3), 507-523.

[8] Murphy, K. R. (1996). Individual differences and behavior in organizations. Jossey-Bass Publishers.

[9] Landy, Frank J., and Jeffrey M. Conte (2013). Work in the 21st century: An introduction to industrial and organizational psychology. John Wiley & Sons.

[10] Motowildo, S. J., Borman, W. C., & Schmit, M. J. (1997). A theory of individual differences in task and contextual performance. Human performance, 10(2), 71-83.

[11] Holland, J. L. (1997). Making vocational choices: A theory of vocational personalitites and work environments. Psychological Assessment Resources.

[12] Daniel Goleman (1995): Emotional Intelligence, Bantam Dell, New York, NY.

[13] Flanagan, D. P. and Dixon, S. G. 2014. The Cattell-Horn-Carroll Theory of Cognitive Abilities. Encyclopedia of Special Education.

[14] Schneider, W. J., & McGrew, K. S. (2012). The Cattell-Horn-Carroll Model of Intelligence. In D. P. Flanagan, & P. L.Harrison (Eds.), Contemporary intellectual assessment: Theories, tests, and issues (3rd ed., pp. 99-144). New York, NY: Guilford Press.

[15] Greenhaus, Jeffrey H., and Gerard A. Callanan, eds. Encyclopaedia of career development. Sage Publications, pp.331-333, 2006.

[16] Digman, J. (1990). Personality structure: Emergence of the five-factor model. Annual Review of Psychology, 41, 417-440.

[17] U.S. Department of Labor. 2002. ONET Ability Profiler Administration Manual. Washington, DC: U.S. Government Printing Office. Retrieved from: https://www.onetcenter.org/dl_tools/AP_zips/AP-AV-deskp.pdf

[18] Mellon Jr, S. J., Daggett, M., MacManus, V., & Moritsch, B. (1996). Development of General Aptitude Test Battery (GATB) Forms E and F. Retrieved from: http://www.onetcenter.org/dl_files/Develop_GATB_ED.pdf

[19] Furnham, A., Dissou, G., Sloan, P., & Chamorro-Premuzic, T. (2007). Personality and intelligence in business people: A study of two personality and two intelligence measures. Journal of Business and Psychology, 22(1), 99-109.

[20] Edwards, J. R. (1991). Person-job fit: A conceptual integration, literature review, and methodological critique. International Review of Industrial and Organizational Psychology, 6, 283-357.

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