Investigating Impact of Human Factors in Cell Production System through Comparison of Two Groups of Workers

Yanwen Dong

1 Cluster of Science and Technology, Fukushima University, Fukushima City, 960-1296, Japan

Abstract: Major studies on cell production have put the emphasis on technical factors such as machine order/layout, family part grouping, workflow sequence, etc., it is still insufficient to investigate how human factors affect the performance of production cells. In order to assess precisely the impact of workers' aptitude on productivity, we have made a series of experimental studies and questionnaire analyses. However, because the workers participated in all of these experiments and questionnaires were university students, it is necessary to clarify whether the results of our experiments and questionnaires obtained from the student workers can also be fitted to general workers. In this paper, we hire 40 workers from the general public and conduct the cell production experiment. Then, we make several statistical comparisons on the differences in working performance and answers to questionnaire between student workers and general workers. We also extend our studies through investigating the impact of workers' age and their gender on the performance of production cells. It was clarified that the assembly times of student workers are generally shorter more than 10% than the general workers; in contrast, there are not significantly large differences in the answers to the questionnaire between the student workers and the general workers. Meanwhile, the workers’ gender and age have significant impact on the performance of production cells.

Key Words: cell production, human factor, individual difference, experimental study, statistical comparison.

1. Introduction

The cell production or cellular manufacturing has become an integral part of lean manufacturing systems; many organizations have applied cell production concepts in manufacturing and service processes. Cell production can provide companies with the flexibility to vary product type or features on the production system in response to specific customer demands. The effects of cell production include reduction in setup time, cycle time, tooling requirements and material handling. Furthermore, it has been confirmed that implementation of cell production can achieve significant improvements in product quality, scheduling, space utilization, control of operations and employee morale [1]–[3].

There have been a number of studies that focused on technical aspects of cell production, such as the best groupings for products and parts, or machine clusters. Some attentions have been directed towards selecting tools, jigs and fixtures, determining process flow, determining cell capacity and selection of equipment. Although technical problems of cell production have been thoroughly researched and many mathematical or computer based approaches have been reported, there is a singular absence of articles that deal with the human factors in cell production. This is because human related issues are typically difficult to quantify [4],[5].

Meanwhile, it has been found that for successful implementation of cell production systems, people who will eventually operate, manage, support and maintain the manufacturing cells should actively participate in their design and development [6]. Wemmerlov and Johnson [7] surveyed 46 user plants with 126 cells and concluded that substantial benefits could be achieved from cell production 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 cell production were related to people, not technical issues.

We have collected literature dealing with human factors in cell production and made a review from three viewpoints: type of study, main factors considered, and methodologies [8],[9]. As described in our previous studies, there are few researches published that consider impact of human factors on performance and implementation of cell production. In addition, the methodologies applied in these researches are mainly questionnaire surveys or case studies. Because of the applied methodologies, most of previous researches could only evaluate impact of human factors comparatively and empirically.

In order to evaluate more precisely impact of human factors, we have made a series of experimental studies [8]–[11], where a laboratory experiment of cell production was conducted to measure performance of production cells by the assembly times, and at the same time, several question-
naries were conducted to measure the workers’ aptitude or identify their individual difference. Because the workers participated in all of these experiments were the students of Fukushima University, it is necessary to clarify whether the experiment results obtained from the student workers can also be fitted to general workers.

In this paper, we put our emphasis on clarifying the difference between student workers and general workers. We conduct a new experiment study to investigate impact of general workers’ gender and age on the performance of production cells. The aim is to improve our researches and make the following contributions:

(1) We hire 40 workers from the general public to conduct the cell production experiment and a questionnaire. Based on the results of cell production experiments and questionnaire, we make two Welch’s t-tests for difference of averages to confirm differences between student workers and general workers.

(2) We extend our researches [12] through conducting an analysis of variance (ANOVA) to investigate how the workers’ individual difference, their gender and age affect performance of production cells.

The remainder of this paper is organized as follows. At first, we introduce briefly the experiment and the questionnaire design. Then we describe the results of experiment and questionnaire, and examine the basic statistics of the assembly times and the answers to questionnaire for the student workers and the general workers. Next, we make two Welch’s t-tests to confirm differences between the student workers and the general workers on the assembly times and the answers to questionnaire respectively. Furthermore, we conduct an ANOVA and a correlation analysis to investigate the impact of workers’ aptitude on performance of production cells. At last, we give some concluding remarks.

2. Cell production experiment design

In order to measure the performance of production cells quantitatively, we designed a laboratory experiment. This experiment uses a toy robot as the virtual product, which was built up of LEGO Mindstorms (see fig. 1) and consists of 106 parts. The assembling process is divided into 17 tasks. As this toy robot can be assembled and disassembled repeatedly, this experiment can be executed at a very low cost.

The experiment is designed on the assumption that the workers have no any experience of assembling the toy robot, and the standard operation time required for every task was neither decided nor informed to the workers.

It is carried out along with the following steps:

[Step 1] At first, we give the workers an assembling manual and then, an instructor demonstrates the assembling tasks through assembling one toy robot practically in front of the workers. Following the instructor’s demonstration, the workers learn the procedure and techniques for assembling the toy robot, and then assemble one toy robot by themselves.

[Step 2] After the instruction and learning, the workers assemble the toy robot in the mode of one-person cell. When doing the assembling tasks, the workers measure the operation time required to complete every task.

[Step 3] In order to measure the learning effect, the assembling operation and time measurement are repeated five times. The assembly time to assemble one toy robot is calculated as the sum of operation times of all tasks. However, the disassembling operation time is not included in the assembly time.

[Step 4] The workers can finish the experiment and go home as soon as they complete assembling operation and time measurement five times. But the experiment will last as long as three hours, even if anyone cannot complete assembling operation and time measurement five times.

3. Questionnaire design

To investigate workers’ attitude and aptitude, such as deftness, participation and other personalities, we designed a series of questionnaires or self-evaluation sheets. In table 1, we showed a questionnaire of thirteen items, which are the common part from two questionnaires conducted for the general workers and the students respectively.

The workers are required to answer the questionnaire after completing the assembly tasks. When answering the questionnaire, a five-point Likert scale: (1) strongly disagree; (2) disagree; (3) neither agree nor disagree; (4) agree; (5) strongly agree, was applied.

4. Basic statistics of experiment results

4.1 Workers from the general public (WGP)

We hired 40 persons as workers from the general public (WGP) and conducted the cell production experiment described above in February, 2014. The demographics of the workers are given as follows:

- Gender
experience, the learning effect could be observed clearly.

assembly times decreased along with increase in the workers’
shorter into 7.6 minutes on the fifth experience. As the as-
times was 13.0 minutes on the first experience and it got
quired for each task. Among 40 workers, 34 of them could
the toy robot in the mode of just four workers. That is, these four workers took much
longer time to complete the assembling tasks.

Table 3 shows the basic statistics of the assembly times for
the general workers after removal of outliers. As the
fluence of outliers has been removed, the medium on the
first experience became very close to the average. At the
same time, the average, standard deviation and range de-
creased altogether on the first, third and fifth experience.
But there is still a difference of more than 2.29 times be-
 tween the slowest worker and the fastest one.

| Statistics           | Experience |
|---------------------|------------|
| Sample size         | 1st  | 2nd  | 3rd  | 4th  | 5th |
| Average             | 11.6 | 10.6 | 9.7  | 7.9  | 7.4 |
| Std. deviation      | 3.2  | 3.9  | 2.2  | 2.1  | 1.7 |
| Minimum             | 19.8 | 20.8 | 13.3 | 12.7 | 11.0|
| Range               | 13.0 | 15.3 | 8.4  | 8.2  | 6.2 |

Table 3 Basic Statistics for WGP (without outliers, min)

4.2 Workers from university student (WUS)

For comparison, we collected another experiment result,
which was conducted during the period from October 2013
to January 2014. The workers participated the experiment
were 60 students from Fukushima University. Among 60
workers, there are eleven female, and their ages are be-
tween 20 and 26. Table 4 shows the basic statistics of
assembly times for the 60 workers.

Table 4 Basic Statistics for WUS (60 workers, min)

| Statistics           | Experience |
|---------------------|------------|
| Sample size         | 1st  | 2nd  | 3rd  | 4th  | 5th |
| Average             | 10.9 | 8.6  | 7.8  | 7.1  | 6.6 |
| Std. deviation      | 2.1  | 1.9  | 1.6  | 1.5  | 1.6 |
| Minimum             | 14.4 | 9.8  | 9.9  | 9.7  | 8.4 |

From table 4, there were 59 workers out of 60 who could

According to the experiment procedure described in sec-
tion 2, these workers assembled the toy robot in the mode
of one-person cell and measured the operation time re-
quired for each task. Among 40 workers, 34 of them could
complete the assembling tasks and time measurement five
times within the time limit of three hours.

Table 2 shows the basic statistics of assembly times for
all of 40 workers, where the experience represents the order
of assembling and time measurement.

| Statistics           | Experience |
|---------------------|------------|
| Sample size         | 1st  | 2nd  | 3rd  | 4th  | 5th |
| Average             | 13.0 | 10.6 | 9.1  | 7.9  | 7.6 |
| Std. deviation      | 6.1  | 3.9  | 3.3  | 2.1  | 2.1 |
| Minimum             | 40.6 | 20.8 | 21.4 | 12.7 | 14.6|
| Range               | 33.8 | 15.3 | 16.5 | 8.2  | 9.9 |

From table 2, it is clear that the average of assembly
times was 13.0 minutes on the first experience and it got
shorter into 7.6 minutes on the fifth experience. As the as-
sembly times decreased along with increase in the workers’
experience, the learning effect could be observed clearly.

Table 1 Thirteen common items of questionnaires

Averagely, the time required to assemble one toy robot
ranges from 5.9 minutes to 20.9 minutes, there is a differ-
ence of more than 2.8 times between the slowest worker
and the fastest one. Therefore, workers’ individual differ-
ence gives a strong impact on performance of production
cells.

Because the mediums of the assembly times are less than
their averages, it is likely that there are several outliers
with very long assembly time. In order to investigate the
fluence of outliers, we applied Grubbs’ test (double-sided
with 95% confidence level) to detect outliers in the assem-
ly times on each experience. As the result, three outliers
were detected from the assembly times on the first experi-
ence, two outliers and one outlier were detected from the
assembly times on the third and fifth experience respec-
tively. These six outliers appeared in the assembly times
of just four workers. That is, these four workers took much
longer time to complete the assembling tasks.

Table 2 Basic Statistics for WGP (40 workers, min)

| Statistics           | Experience |
|---------------------|------------|
| Sample size         | 1st  | 2nd  | 3rd  | 4th  | 5th |
| Average             | 11.1 | 9.4  | 8.2  | 7.7  | 7.3 |
| Std. deviation      | 3.2  | 3.9  | 2.2  | 2.1  | 1.7 |
| Minimum             | 6.8  | 5.5  | 4.9  | 4.5  | 4.8 |
| Maximum             | 19.8 | 20.8 | 13.3 | 12.7 | 11.0|
| Range               | 13.0 | 15.3 | 8.4  | 8.2  | 6.2 |

Outliers appeared in 4 workers

- male: 9
- female: 31

- Education
  - junior high school: 5
  - high school: 15
  - university: 14
  - graduate school: 1

- Age
  - <20: 2
  - 20-29: 21
  - 30-39: 3
  - 40-49: 8
  - 50-59: 1
  - unknown: 5

- Experience

Q1 I like making something
Q2 Fine work is my favorite
Q3 I think my hand is deft
Q4 I am going to actively participate in this experiment
Q5 The experiment manual was very comprehensible
Q6 This experiment was interesting
Q7 This experiment was meaningful
Q8 The assembly tasks were repeated too many times
Q9 This experiment was difficult
Q10 This experiment was monotonous and boring
Q11 In order to raise efficiency, I had devised for myself
Q12 I worked actively during this experiment
Q13 I was not good at fine work

- male: 9
- female: 31
complete the assembling tasks and time measurement five times within the time limit of three hours. The proportion of workers who couldn’t complete the assembling tasks and time measurement five times is significantly less than the workers from the general public. This is because that the workers from university students are in the major field of engineering and have been trained systematically in experimental skills. Furthermore, the average of assembly times on the first experience was 10.9 minutes and it got shorter into 6.6 minutes on the fifth experience, all of these times are shorter than that for the workers from the general public.

Although the mediums of assembly times are very close to their averages, there are ten outliers in total that were detected from the assembly times on five experiences, through applying Grubbs’ test (double-sided with 95% confidence level). As shown in table 5, these ten outliers were observed in the assembly times of six workers. There was no difference between the student workers and the general workers in terms of the proportion of workers with outliers. After removal of outliers, there is a difference of more than 2.28 times between the slowest worker and the fastest one, this difference is also very close to that of workers from the general public (2.29 times).

| Experience | 1st | 2nd | 3rd | 4th | 5th |
|------------|-----|-----|-----|-----|-----|
| Sample size | 57  | 59  | 58  | 58  | 56  |
| Average     | 10.4| 8.5 | 7.5 | 7.0 | 6.4 |
| Medium      | 10.3| 8.3 | 7.7 | 6.8 | 6.3 |
| Std. deviation | 2.4 | 2.0 | 1.7 | 1.7 | 1.3 |
| Minimum     | 6.2 | 5.4 | 4.7 | 4.3 | 3.9 |
| Maximum     | 15.7 | 13.9 | 10.9 | 11.9 | 8.9 |
| Range       | 9.5 | 8.4 | 6.2 | 7.6 | 5.0 |
| Outliers    | 3   | 1   | 2   | 1   | 3   |

Outliers appeared in 6 workers

5. Comparison of assembly time

Fig. 2 shows averages of assembly times for the general workers (WGP) and the student workers (WUS), where "WGP-whole" and "WUS-whole" represent the averages for all workers; "WGP-no outlier" and "WUS-no outlier" represent the averages after removal of outliers. From fig. 2, the averages of assembly times for the general workers are obviously longer than that for the student workers. Meanwhile, the difference of averages between the general workers and the student workers varies according to the experience and it decreases to some extent after removing outliers.

Furthermore, we applied Welch’s t-test to confirm if the difference of averages of assembly times between the student workers and the general workers is significant. Table 6 shows the result of Welch’s t-test for the difference of averages of assembly times after removal of outliers.

From table 6, it is obvious that:

(1) The proportion of the valid samples in the group of student workers is larger than that in the group of general workers for four experiences out of five. As mentioned above, this is because some workers from the general public have not been trained systematically in experimental skills, and so that they have lower ability than the student workers to fulfill the assembling tasks and time measurement according to the required procedure.

(2) The averages of assembly times for the general workers are longer than that for the student workers on every experience. The differences of averages between the general workers and the student workers range from 10.3% to 19.9%. Meanwhile, two-tailed p-values of Welch’s t test for the differences of averages of assembly times on the second experience to fifth experience are less than 5%, and p-value on the first experience is 5.45%, which is only slightly over 5%. Therefore, there is significant differences in the averages of assembly times between the general workers and the student workers. We think these differences come from that the student workers who were selected by the entrance examination, have a relatively high level of operation ability.

(3) Comparing the minimums and maximums of assembly times shown in table 3 and table 5, it can be observed that the minimums and maximums for the general workers are also larger than that for the student workers respectively. In addition to the differences in the averages, it is clear that the assembly times of the student workers is generally shorter than that of the general workers.

6. Comparison of questionnaire answers

As described in section 3, we designed and conducted two questionnaires to the workers from the general public (WGP) and the workers from university students (WUS) respectively. For thirteen common items of the two questionnaires, there were 38 valid answers collected from the general workers, and 58 valid answers collected from the student workers. In table 7, we showed the result of Welch’s t-test for the difference of averages of answers to the thirteen questionnaire items between the general workers and the student workers.

From table 7, it is obvious that:
Among thirteen questionnaire items, there are nine items that the averages of answers from the general workers have no significant difference with that from the student workers. It is therefore that both the general workers and the student workers gave significantly close answers to most of questionnaire items.

There are three items: Q4, Q6 and Q7 that the answers from the general workers are significantly higher than the answers from the student workers. Meanwhile, there is just one item: Q8 that the answers from the general workers are significantly lower than the answers from the student workers. As Q4 (I am going to actively participate in this experiment), Q6 (This experiment was interesting) and Q7 (This experiment was meaningful) are positive questions (the higher answer is more desirable); in contrast, Q8 (The assembly tasks were repeated too many times) is a negative question (the lower answer is more desirable). Therefore, the general workers gave more positive answers than the student workers. We consider that this difference was caused from the fact that the student workers participated the experience without any monetary compensation; in contrast, the general workers received monetary rewards.

The largest difference of -38.2% occurred in the average of answers to Q8 between the general workers and the student workers, it means that the student workers felt more strongly that the assembling tasks were repeated too many times. This result is because most of the general workers already have work experience at a factory and they have become accustomed to repetitive operations. As the differences in the averages of answers to Q4, Q6 and Q7 between the general workers and the student workers are 9.3%, 11.8% and 12.8% respectively, we consider that there are not large differences in the answers to the questionnaire between the general workers and the student workers if the influence of workers’ working experience and monetary reward was taking into account.

### 7. Impact of gender, learning effect and individual differences

As the assembling operation is repeated, the workers can learn the skills and techniques from experience and improve gradually their operation efficiency. To investigate the impact of learning effect, workers’ gender and workers’ individual differences on the assembly times, we conducted an analysis of variance (ANOVA) based on the experiment results of the general workers.

For the ANOVA, the dependent variable is the assembly time and the three independent factors are A) experience or assembling order that represents learning effect, B) gender of workers and C) workers’ name that represents individual difference, have significant impact on assembly time.

From table 8, it is clear that:

(1) As the p-value is zero, three factors: the experience (learning effect), gender of workers and workers’ individual difference, have significant impact on assembly time.

(2) Only 27.1% of the variance of the assembly times was caused by the experience (learning effect), and 62.5%...
of that was caused by the workers’ gender and individual difference. It is clear that the workers’ personality has a stronger impact than the learning effect on performance of production cells, and therefore selection of workers is very important to implement cell production successfully. This result is very close to the observations reported in our previous studies [8],[9].

(3) The workers’ gender has significant impact on the assembly times. It caused 12.3% of the variance of the assembly times, and the impact is not as strong as learning effect. In addition, the average of assembly times on five experiences for the male workers is 10.89 minutes and it is longer than the female workers for 2.12 minutes. Hence, it is reasonable to argue that female workers are slightly more suitable to assembly operation than male workers.

Furthermore, in order to clarify the relationship between workers’ age and performance of production cells, we calculated the linear correlation coefficients between the general workers’ age and the assembly time on every experience, where the valid sample is 33 after the workers of unknown age and with the outliers in their assembly times were removed.

Table 9 shows the correlation coefficients and corresponding p-values. As the p-values on the second experience to the fifth experience are all less than 5%, the assembly times correlate significantly to workers’ age. However, the correlation coefficients range from 0.158 to 0.276, workers’ age has weak positive relationship to assembly time. Therefore, older workers are likely inefficient in production cells but this trend is not strong. We consider that this is because the labor load for the experiment is relatively light and the experiment lasted only three hours, it does not need more physical strength for the workers to do the assembling tasks.

Table 9 Correlation between workers’ age and assembly time

| Experience | 1st | 2nd | 3rd | 4th | 5th |
|------------|-----|-----|-----|-----|-----|
| Corr. coeff. | 0.028 | 0.158 | 0.199 | 0.160 | 0.276 |
| p-value   | 0.6716% | **1.63%** | **0.23%** | **1.81%** | **0.01%** |
| Valid sample: 33 |

8. Conclusion

This paper aimed mainly at clarifying the difference between student workers and general workers, we have conducted two Welch’s t-tests and an ANOVA based on the results of cell production experiment and answers to questionnaires. The main results of this study can be summarized as the following:

(1) Among 40 general workers, six of them could not complete the assembling tasks and time measurement five times within the time limit of three hours; in contrast, there was only one in 60 student workers. The workers from the general public differ largely from the student workers on the ability to fulfill the assembling tasks and time measurement.

(2) The averages, minimums and maximums of assembly times for the general workers are all larger than that of the student workers. There are significant differences in assembly times between the general workers and the student workers. We think these differences come from that the student workers were selected by the entrance examination and have a relatively high level of operation ability.

(3) For thirteen common items of the two questionnaires conducted to the student workers and the general workers respectively, there are nine items that the averages of answers from general workers have no significant difference with that from student workers. Although there were four items out of thirteen that the averages of these answers from the general workers differ significantly from that from the student workers, these differences were caused by workers’ working experience and monetary reward. On the whole, there are not large differences in the answers to the questionnaire between the general workers and the student workers.

(4) Both the learning effect and the individual difference of the general workers have significant impact on performance of production cells. The effect of the workers’ individual difference (50.2%) is stronger than the learning effect (27.1%). Comparing to the results for the student workers reported in our previous studies, there is almost no difference between the student workers and the general workers in the impact of the workers’ individual difference on performance of production cells.

(5) Female workers could complete the assembling tasks with significantly shorter time than male workers. On the other hand, workers’ age has just weak negative influence on performance of production cells.

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Yanwen Dong

is a professor in the cluster of science and technology at Fukushima University. He received his bachelor degree in 1982 and a master degree in 1984 from University of Science and Technology Beijing, China. He also received Ph.D in 1996 from the Osaka Prefecture University, Japan. He worked in University of Science and Technology Beijing as a lecture from 1984 to 1995 and in Faculty of Economics, Fukushima University as an associate professor from 1997 to 2004. His current research interests include cell production system, production scheduling, data mining and management information system.