Is Work Really Innovated ? :

A case study on work, workers' behaviour, and the role of skill after technological change among Japanese shipbuilders

Yuzuru Utsunomiya

Abstract

The purpose of this study is to examine whether technological change affects workers' behaviour and the role of their skills in the period of skill shortage. Two characteristic shipbuilders are compared. We conducted a field survey to collect data on workers' work time using the work sampling method and information on their work through open-ended interviews. We use MANOVA for the collected evidence.

The results show that the effects of technological change definitely exist. However, workers' behaviour is not affected by the change. Their skill for autonomous work persists and contributes to the production technology.

Key words: work, skill, shipbuilding, production technology progress

Acknowledgement

This research was partially supported by the Ministry of Education, Science, Sports and Culture, a Grant-in-Aid for Young Scientist (B), 2007, 18730248. The support and cooperation of Co. X and Co. Y are greatly appreciated.

Introduction

The purpose of this study is to examine how technological change affects work and workers' behaviour and to investigate the role of their skill.

Controversy over skill is one of the major aspects of management study, sociology, psychology, and other disciplines. There have been many surveys and researches on this aspect (Osterman, 1985; Penn, 1986; Attewell, 1987; Form, 1987; Zicklin, 1987; Capperli, 1994; Lewis, 1995; Agnew, 1997; Leigh, 1999).

For example, in their survey on wage at a printing industry, Wallace and Kalleberg (1982) noted that after technological progress, decision making and apprenticeship have not been necessary. Instead, authority over production management has been delegated to managers. As a result, workers' skill levels have decreased. We should emphasize that in their article, the effect of technological change is estimated to be different based on the type of industry. However, the scope of such a study should not be so wide. Oliver (1982) summarized past research and pointed out the problem inherent in them. According to him, the concept of skill has four phases. First, it implies the ability to solve unexpected problems. Second, it implies a person's ability to work independently. Third, it implies a person's ability to complete his own work first. Fourth, it implies a man who is compliant. According to the article, these diverse phases of the concept of skill developed from the usage of the concept. Vallas (1988) explained the issue in the case of the telecommunication industry using Spenner's concept and providing examples of apparatus. He concluded that from the 1950s to the 1980s, the skill level has increased. However, after this period, a deskilling tendency has been observed.

In this context, the components of workers' skill have been clarified. For example, Bright (1958) mentioned that skill consists of the following 12 elements: physical effort, mental effort, manipulative skill, general skill, education, experimentation, exposure to hazards, undesirable job conditions, responsibility, decision making, and influence on productivity. Based on these concepts, he discussed the influence of automation on workers' skill. Further, he generally concluded that as automation leads to progress, the workers' skill level decreases. Spenner (1983) summarized that the characteristics of the components of skilled workers' skill consist of two elements – 'autonomy-control' and 'substantive complexity'. According to Rolfe (1990), skill consists of the following six components: the complexity of tasks, knowledge, range and variety of tasks, decision making and judgment on the process or product, control over the organization of work, and supervision. Cooke (2002) noted the importance of maintenance skills. Based on a survey on maintenance shops in various industries, the successful operation of machines each of the shops are equipped with is a source of job satisfaction.

In the context of the controversy over skill, the relation between vocational training and skill or that between a manager's role and skill has also been discussed. For example, Katz (1955) noted that skills consist of technical skills, human skills, and conceptual skills. The importance of these skills is dependent on the position of workers. Koike (1998) compared the skill development method at a car assembly plant in Japan and one in America. He noted that there are two types of work- 'usual' work and 'unusual' work. The skilled worker's role is to solve and deal with a problem in the latter type of work.

In the course of this controversy, the environment of workers and companies has changed. Today, we face a problem called skill shortage. This problem implies that we cannot maintain a level of highly advanced skill in maintenance shops due to the retirement of skilled and elderly workers. Due to this process, the skill, know-how, and other precious resources that workers possess become obsolete (Delong, 2004; Dychtwald, et al., 2006). As a result, we cannot maintain the required quality of products and safety in the work environment. In fact, although this problem appears to be overestimated (Watson, Webb & Steven, 2006), the condition in some industries is serious. For example, Smith (2004) notes that within 15 years, 32 thousand people will retire from nuclear power plants, and it will not be possible to maintain the processes that perform important activities. Therefore, as a resolution, training programs or databases on skill should be created. At a water supply industry (Olstein, 2005), a similar problem has occurred. The major problem with regard to skill is not whether the skill level increases or decreases but how we transfer the skills.

In this article, we investigate workers' behaviour when skilled workers demonstrate the abovementioned components of skill to preserve them.

Method

Subjects

We selected two shipbuilders, Co. X and Co. Y, which are located in Nagasaki Prefecture in eastern Japan. Co. X is a typical shipbuilder that builds steel ships with the modular construction method. It has 120 employees in all. Co. X has been building steel ships for fisheries, inspection, and other activities since 1952. They can build ships up to 700 G/T (gross tonnage; refers to the size of ships) and repair up to 1000 G/T. They have the following six sections: sales, design, steel works, fitting, material management, and general affairs. No workers' union exists. Co. Y mainly builds small wooden ships that are used for regional boat competitions, using the conventional techniques of building ships. In addition, they repair and remodel the FRP (fibreglass reinforced plastics) fishing boats allocated to them. It has three employees.

The reason we selected these companies as subjects for this study is that they preserve the basic production technology in addition to applying the latest technology. Originally, ships were made of wood. After the invention of steel plates suitable for ships, some shipbuilders began to utilise it as material for the hull, mast, ladder, and other components of ships. Simultaneously, the size of ships has continued to increase. In addition, shipbuilders have applied various new production technologies, such as modular construction, that enable them to build ships more rapidly and continuously, as in the case of automobile assembly. On the other hand, some small ships for coastal fisheries and other activities have been built with wood by small shipbuilders. In addition, due to the lack of appropriate wood and skilled shipwrights, since the 1960s, some shipbuilders have built ships with FRP. As such, while some shipbuilders have witnessed various technological progress, others continue to use basic shipbuilding technology. Co. X is a typical case of the former type of shipbuilder, and Co. Y is one of the latter type of shipbuilder. In this study, by comparing these companies, we investigate the effect of technological progress on work.

Work and workers' behaviour in the shipbuilding companies

To discuss the relation between technological progress and work, it is important to note the characteristics of the shipbuilding process and the characteristics of work. First, we discuss the characteristics of the shipbuilding process and production technology.

Although the production technology used in each of the companies appears to be different, the role of the shipbuilding process appears to be similar in the two companies. We can classify the characteristics as follows.

1. Fabrication:

Fabrication is the process of cutting steel or wood plates into pieces and shaping them according to drawings. In Co. X, workers in charge of this process work with a press machine and use the line heating method. It is a method for bending steel plates into an appropriate shape using a gas torch and water. In particular, workers heat the surface of a steel plate and cool it with the above-mentioned tools, such as drawing lines; they then deform the steel plate along the lines heated. After repeating such work, the plate has been shaped into an appropriate form. This work requires skilled and experienced workers. In particular, it is difficult to decide when, where, and how long plates should be heated. Hence, some shipbuilders have been developing a mechanized technique (Iwasaki et al., 1975); however, many steel shipbuilders continue to use the older technique.

In Co. Y, workers in charge of this process work with hand saws, tip saws, jigs, fixtures, and some tools for measurement. In particular, workers draw lines on the surface of wooden plates and then cut them with the specified tools. In particular, drawing appropriate curves to reduce the wastage of material is difficult. Similar to the process in Co. X, this process requires highly skilled workers.

2. Assembly:

Assembly involves the assembly of parts shaped during the fabrication process based on the drawings, and mounting them into a ship. In Co. X, workers construct blocks that constitute the main components of ships, and then mount and weld them in the dockyard. This process requires great accuracy. In addition, to make the hull waterproof and ensure its intensity and attractive shape, workers have to accurately lap the joints around which blocks are welded. Occasionally, when the joints do not lap as per the design, they have to adjust the shape around them. In particular, they weld jigs and fixtures on the blocks in order to push and pull them while adjusting their position.

In Co. Y, workers assemble parts fabricated during the previous process into a hull using a boat nail. Before jointing them, they use the lapping method to make it waterproof. In particular, they saw the clearance between two plates by means of thin and hard blade saws. For this, concavity consists in the clearance are cut, and we can contact the mating contacts precisely and integrally with each other. According to all the shipwrights at Co. Y, this process is the most difficult. During the survey period, we had an opportunity to perform or help in some types of jobs conducted at the workplace. However, the workers do not perform the lapping process conducted by us.

3. Outfitting:

Outfitting is the process of creating and setting some structures required for voyages. For example, it includes mounting masts, funnels, bits, and other equipment. The piping for hydraulic machines and pumps is also included in the process.

4. Stern Fitting:

Stern fitting is the process of adjusting position and form. In particular, it involves performing adjustments by chipping away the inside of the stern frame and gudgeon by means of a special lathe invented for such work. The workers assemble these apparatuses for use only when they undertake such work. Machinery workers at machine fitting shops are mainly in charge of this process. We can certainly regard this process as a part of the machinery fitting process.

This job is mainly performed at Co. X. Occasionally, workers in Co. Y perform such work to repair the equipment developed by other shipbuilders.

5. Machinery Fitting:

Machinery fitting is the process of mounting engines, pumps, and other machines into place according to drawings. Parts or equipment are also processed by means of machine tools such as lathes and milling machines. Meanwhile, people in charge of fitting and those in charge of machinery works occasionally cooperate with each other. Adjusting the condition and position of machines available for use is also an important function. For example, fitting and calibrating the position of shafts equipping both the main engine and reduction gear into a line is a major task that workers in charge of this process are engaged in.

Classifying the work process based on the role a task entails

Second, we discuss the characteristics of the work process conducted during each of the above-mentioned processes. In other words, we define and develop the perspective for examining them. According to Kanawaty (1992), this work process involves the five activities mentioned below:

1. Operation

It indicates the main steps in a process, method, or procedure. Usually, the part, material, or product concerned is modified or charged during operation.

2. Inspection

It indicates the inspection for quality and check for quantity.

3. Transport

It indicates the movement of workers, materials, or equipment from place to place.

4. Temporary Storage or Delay

It indicates a delay in the sequence of events, for example, work pending between consecutive operations, or any equipment that is laid aside and for which a temporary record is required.

5 . Permanent Storage

It indicates a controlled storage for storing material or from which these materials are trans ported under some form of authorization, or an item that is retained for reference purposes.

Such a perspective is developed from Taylor's scientific management (Taylor, 1998) and has been improved by many followers. Currently, many researchers and practitioners apply this perspective to work-related research and job analysis (Brannick and Levine, 2002).

By observing the work at these companies, we can develop a model on work using the given classification. In most cases, the production processes commence with transportation activity. For example, the fabricated parts that are used to construct the hull are transported to the shop. Similarly, the tools for performing welding on the deck are also transported. Next, the workers begin the operation activity and finally, the inspection activity is completed.

We need to emphasize the fact that the operation and inspection activities form a feedback loop process in the work process. To satisfy the specifications and quality presented in the drawings, such as forms, length, tolerance, and other conditions, workers repeat their calibration during the operation activity, using information from the inspection activity. Typically, workers cannot fulfil the specifications with regard to quality at one time. In addition, during this process, workers do not only consider the processes and activities but also envisage the form to be achieved. We assume that the workers' work time allocation in such a feedback loop process presents data on workers' behaviour. Further, when we regard the transport and inspection activities as a type of preparation, the work processes consist of two activities, namely, 'Operation' and 'Preparation', as shown in Fig. 1. In short, we can examine and analyze the characteristics of workers' behaviour by measuring their time for operation and preparation. Unexpectedly, this process is similar to the work study conducted by F. W. Taylor, the father of modern management studies.

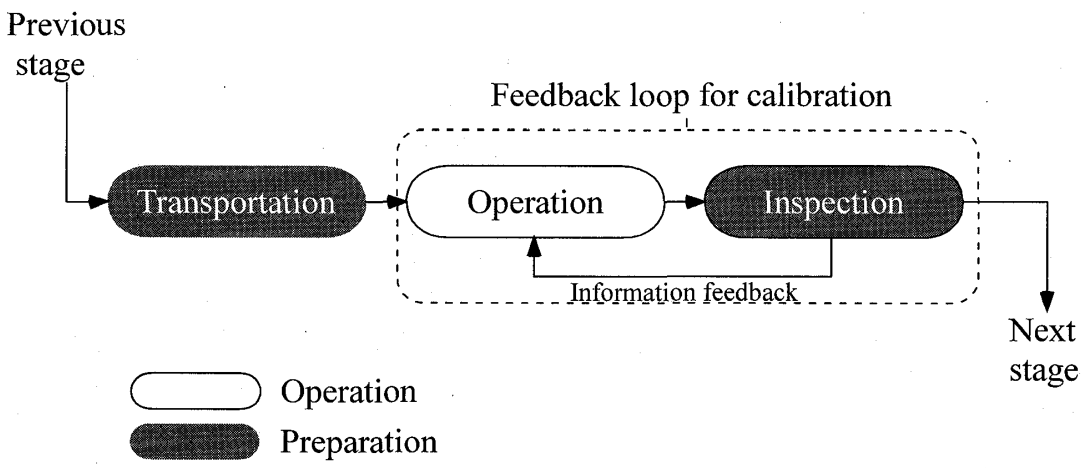


Figure 1 Feedback loop at work

Procedure

Since our major interest is the behaviour that can be observed based on the variance in work time, we measured the work time for operation and preparation activities. This was done with a view to long-term participation from all workers. At Co. X, we conducted work sampling from July 2005 to January 2006. At Co. Y, we conducted sampling from May 2006 to March 2007. From the survey, we collected data on work time and factors presented below that appeared to affect the variance in work time.

1. Company:

It indicates the company that workers belong to. This factor indicates the difference of technology used for shipbuilding. There are two groups referred to as Co. X and Co. Y.

2. Stage:

It indicates the stage that workers are in charge of. This factor reveals the difference in the characteristics of work that workers perform. As mentioned above, there are six groups referred to as 'fabrication', 'assembly', 'mount', 'equipment', 'stern', and 'machinery'.

3. Frequency:

It indicates the number of times that workers repeat the feedback loop. This indicates the difficulty of the work that workers undertake.

Simultaneously, we interviewed workers and managers with regard to the work and technology using the open-ended method.

Using the collected evidence, we carried out a MANOVA to examine whether the factors affect the work time variance. For details on MANOVA, see Hand and Taylor (1987). We estimated the effect of process change using the interaction between the company and stage factors. Before performing the analysis, due to the statistical assumption of the method of analysis, we translated the work time by logarithmic translation. For information on this translation, see Sokal and Rohlf (1995). We estimated the effect of the change in workers' behaviour using the interaction between the company factor and frequency factor. For the analysis and drawing of graphs, we used the statistical analysis environment R (version 2.5.0).

Results

Technological change and its influence on workers

As shown by the National Research Council (U.S.). Committee on National Needs in Maritime Technology (1996), the shipbuilding industry has experienced various technological progress for several decades after World War II. This has also changed the nature of work. For example, in Co. X, the number of workers at the loft shop has decreased as a result of adopting the 2D CAD system. As they purchase wooden products like chairs and other furniture from outside vendors, the carpentry shop has been closed down and workers in the shop have moved to other shops. Meanwhile, as new equipment is mounted, new types of work such as stern fitting and machine fitting are required. In addition, due to the development of leader, sonar, and many types of electronic nautical instruments, a new category of workers has emerged. In particular, in this article, we note that progress in the fabrication and assembly processes indicated below appear to affect work characteristics.

1. Fabrication:

In both wooden and steel shipbuilding, this process entails a heavy load on workers. This is because they are occasionally required to carry parts or plates fabricated during a previous process by hand under working conditions that are extremely hot. To resolve this problem, workers urgently require powered machine tools such as hoist cranes or press machines. In addition, in Co. X, workers involved in this process had formerly performed their jobs only with the line heating method. As a result, workers on the ships were forced to work under extremely high temperatures, and the use of man-hours was necessary. After press machines were introduced in the 1990s, the use of the machines can be combined with the line heating method. As a result, the workload has decreased and productivity has improved during this stage.

In Co. Y, tip saws and electric planers have been used for 30 years, in addition to handsaws and hand planers. Such powered tools have been used for cutting wooden plates whose length exceeds 10 m. A worker Z in Co. Y said the following:

> 'By using these powered tools, our workload has decreased'.

2. Assembly:

Originally, shipbuilders attached or welded ships' hull plates, keel, frames, beams, and other parts on the building slip. In Co. Y, they continue to build ships in this manner. However, as the size of ships increases, the activities required for assembly become more difficult because a great number of parts are involved, and it is difficult to coordinate the procedure for assembly. Block construction is a technique for assembling the hull. A 'block' implies a unit or modular that forms a part of the hull. Before assembly, workers build the blocks at another site and pull them onto the build slip. After this, they build blocks to build a ship. By adopting such a method, they can build ships just like automobiles. The invention and adoption of this method contributed to the speed, safety, effectiveness, and quality of building ships. As a result, productivity has increased dramatically. Terai, Kurioka, and Takeuch (1973) state that such a method was first applied to build a Japanese navy vessel in WWII. After the war, it has been completely diffused at the Japanese shipyard.

With this progress, the working conditions have improved. In particular, block construction under the roof, which is not affected by weather conditions, not only improves productivity, quality, and the accuracy of products but also decrease workers' load and fatigue. A production manager B in Co. X said the following:

'Because we can work under the roof, workers are protected from rainfall and wind. In addition, we can maintain the density of carbon dioxide brow to cover the welded area and increase the quality of welding'.

However, the effects of natural conditions persist in both Co. Y and Co. X as tidal movement affects the progress of production. In Co. Y, wooden materials are affected by the natural conditions, and workers have to handle them carefully. A worker D in Co. Y said the following:

'Without allocating wooden materials for each side of the hull plate appropriately, the weight of the hull will differ. As a result, the transverse balance will change, thus making it unsuitable for navigation'.

A worker C in Co. X said the following:

'During neap tides, we cannot work comfortably around the stern section because sea water covers the dock slip'.

Based on such production technology, workers at the companies manage their processes autonomously. Indeed, in both the companies, the drawings and information about the due date are provided to the workers. In principle, the workers develop work schedules and processes to create products presented in the drawings. They prepare materials while considering the work process. For example, a worker Z in Co. Y stated the following while he was working:

'Because this plate is required for the operation tomorrow, I have to dry it'.

If necessary, workers improve the machines and make the jigs used in the companies. In all the shops in the companies, many types of jigs and fixtures are used. By means of these tools, they can perform their jobs with high speed and safety. Note that sometimes, the same jigs are used in the companies. For example, for tracing the form of the surface on other pieces, they use a piece of the materials gathered from somewhere.

Work time

Fig. 2 shows the transitions of the means of work time observed in the two companies. In Co. Y, the work time for operation activity indicates a tendency to increase (Kendall's rank cor-

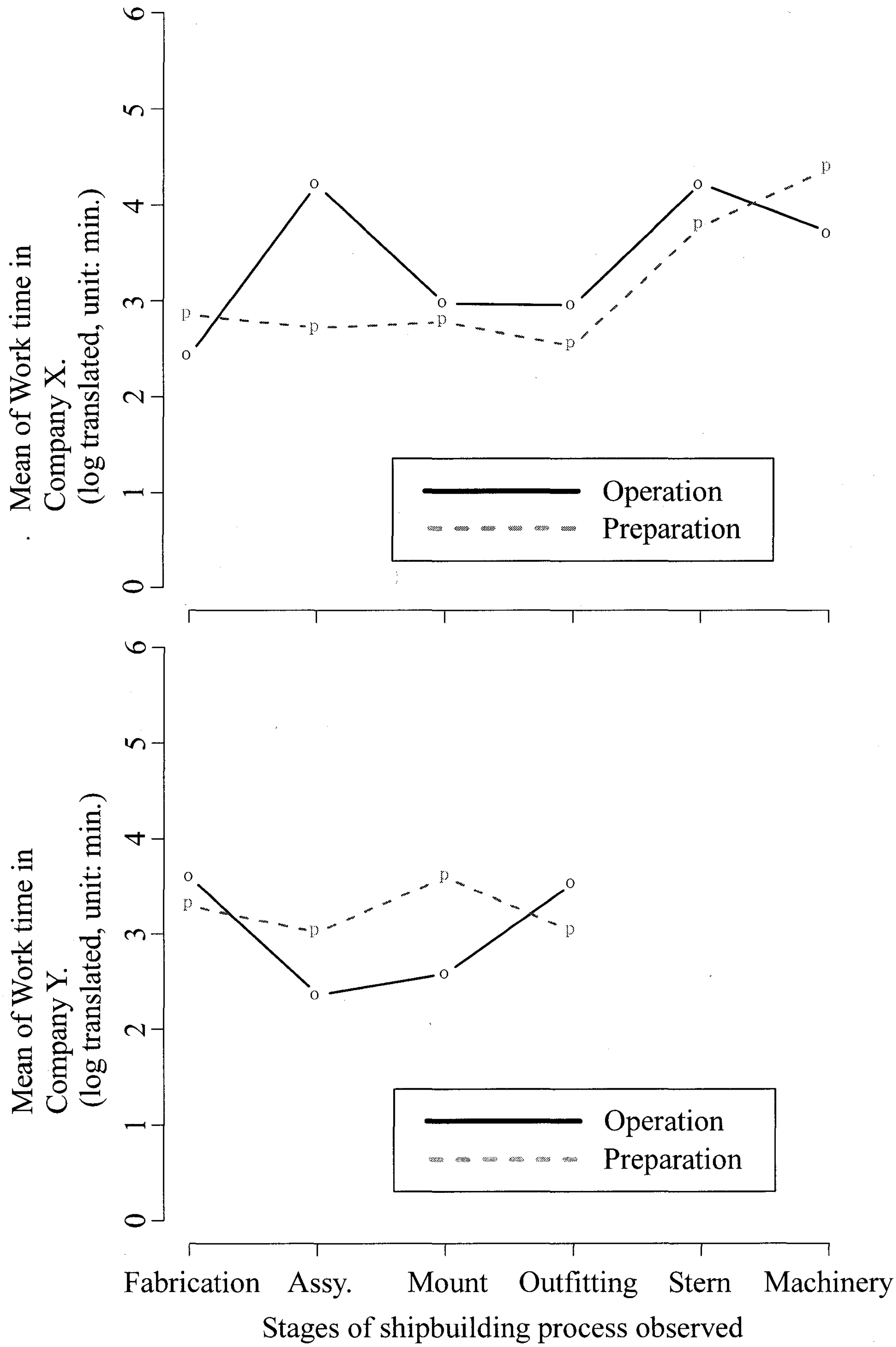


Figure 2 Mean of work time at each stage in the process of shipbuilding

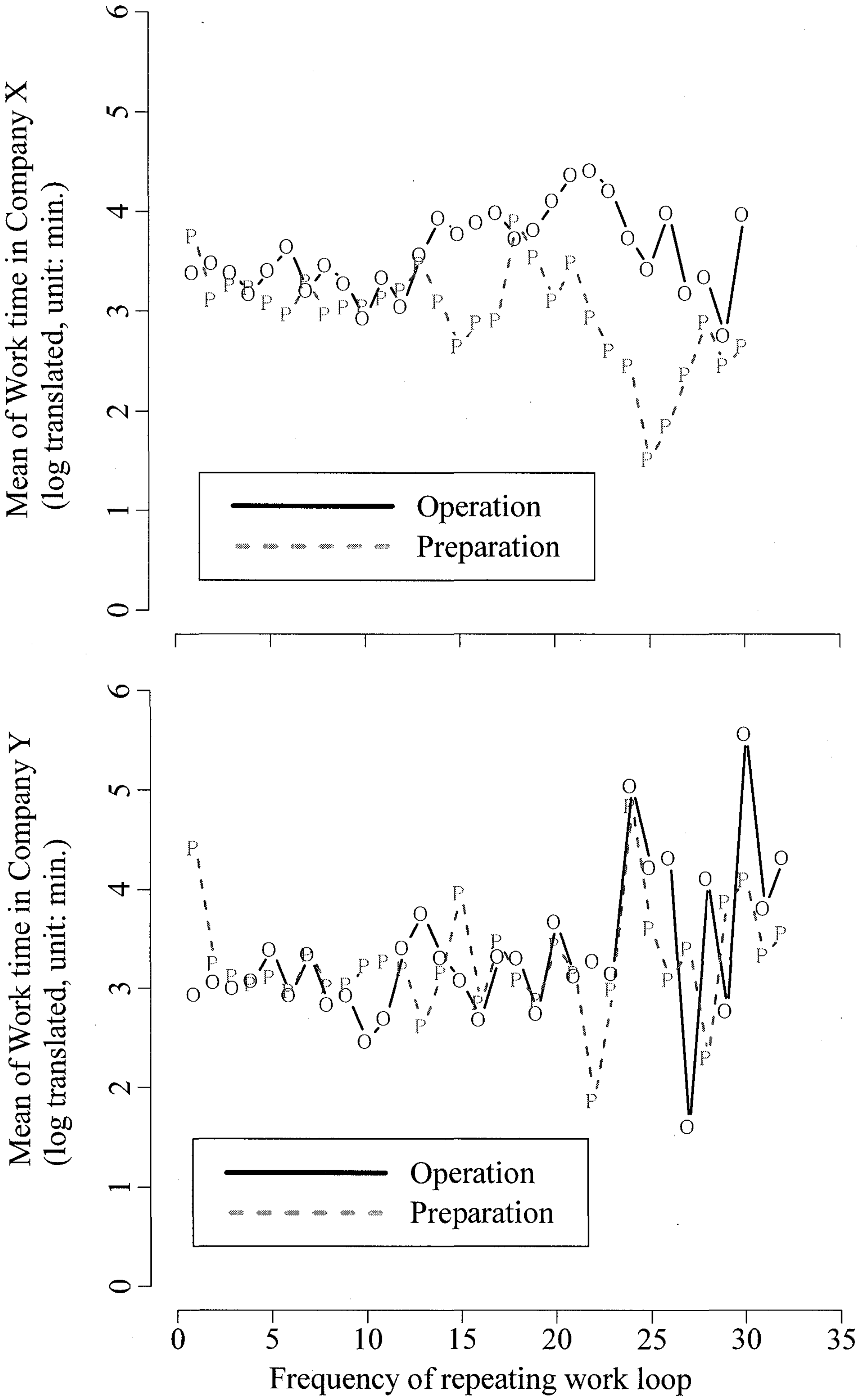
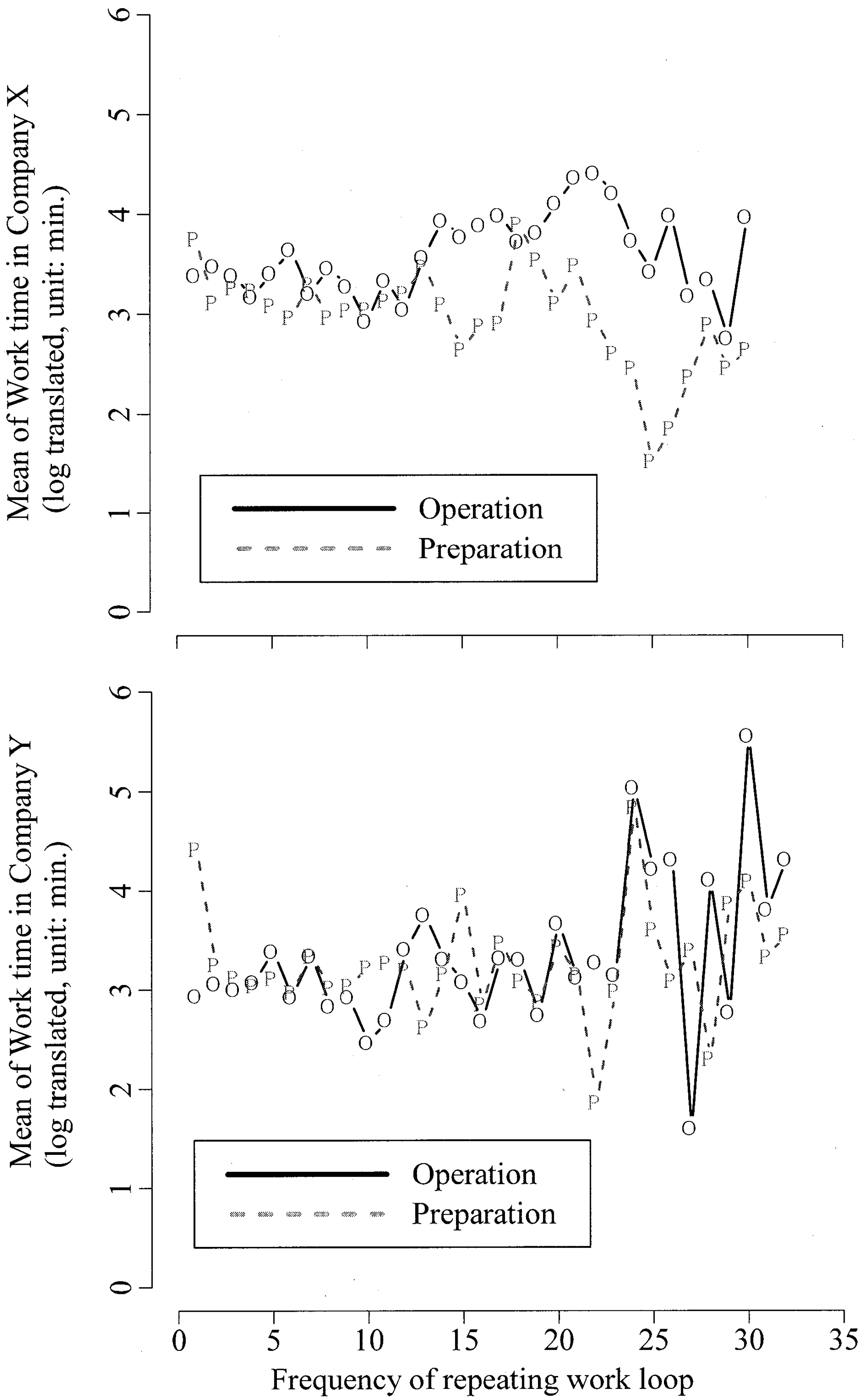


Figure 3　Mean of work time by frequency of repetition


Mean of Work time in Company X
(log translated, unit: min.)
Operation
Preparation
Mean of Work time in Company Y
(log translated, unit: min.)
Operation
Preparation
Frequency of repeating work loop

relation, tau = 0.297, p-value = 0.02). The work time for preparation activity also indicates a tendency to increase (tau = 0.109, p-value = 0.38). The work times observed in Co. X indicate a different tendency from that in Co. Y. The work time for operation tends to decrease (tau = -0.227, p-value = 0.08) as the frequency of the feedback loop increases. The work time for preparation also tends to decrease (tau = -0.404, p-value = 0.002). However, note that in both the companies, at the initial stage, the allocation of work time for preparation is longer than that for operation. In addition, the work time for operation is nearly equal to that for preparation.

Fig. 3 shows the means of work time at each production stage observed in the two companies. According to the figure, we have to note that changes in work time allocation have occurred at three stages: fabrication, assembly, and mount. In the case of the fabrication process in Co. Y, the means of work time for preparation are shorter than those for operation. However, in the case of Co. X, for the fabrication process, the means of work time for preparation are longer than those for operation. For the assembly and mount processes in Co. Y, the means of work time for preparation are longer than those for operation. However, in Co. X, for the assembly and mount processes, the means of work time for preparation are shorter than those for operation. The relation between the two processes in these companies has changed. The major effect of technological progress appears to be on these processes, which are regarded as the former processes of shipbuilding.

For descriptive statistics on work time sorted by company, stage, and content of work, and those on work time sorted by company, frequency of the feedback loop, and content of work, see the appendices.

Table 1 provides a summary of the MANOVA results. As seen in the table, all factors are significant at the 5% level. The interaction of company and stage, which represents technological change, is a significant factor at the 5% level. However, the interaction of company and frequency of the feedback loop, which represents a change in workers' behaviour, is not significant

Summary of the MANOVA results

Factor	Df	Pillai	Approx. F	num Df	den Df	p-value
Company	1	0.052	24.953	2	907	2.808e-11
Stage	1	0.089	44.491	2	907	< 2.2e-16
Frequency	1	0.021	3.928	2	907	5.43e-5
Company * Stage	1	0.037	17.358	2	907	4.002e-08
Company * Frequency	1	0.001	0.593	2	907	0.553
Residuals	908					

Table 1 Summary of the MANOVA results

at the 5% level.

Conclusion

In the present work, surveys on work time and process management have been conducted in the case of two shipbuilders, Co. X and Co. Y. Comparing workers' work time and behaviour in Co. Y, which uses conventional production technology, with those in Co. X, which uses advanced production technology, we discuss the relation between technological progress and workers' behaviour.

In about 50 years, shipbuilders have experienced many aspects of technological progress, such as modular construction and automated welding. The impact of such process improvements on production management, machines, and working conditions can reduce the workload caused by the working conditions such as high temperature and heavy materials. Efficiency also appears to increase. The relation with regard to time allocation has been inverted between companies using basic production technology and those using advanced production technology. Indeed, technological change affects workers' behaviour. Table 1 shows that the interaction of company and stage, which is regarded as a factor that represents the effect of technological change, is significant.

However, we cannot conclude that workers' behaviour has changed as a result of technological progress. According to the results of the interview, workers in these companies plan their work procedures autonomously. They occasionally select the appropriate materials for their job. Concerning the feedback loop process, Table 1 shows that there is no significant difference between the two companies. Process management and improvement by workers also remain unchanged. In these companies, the work time for operation is nearly identical to that for preparation.

To summarize, technological progress certainly has an impact on work efficiency. However, it does not affect workers' behaviour as we expected. Autonomous work and process management persist after technological progress. Such phenomena support the concept of 'autonomy-control', which Spenner (1983) demonstrates as a component of skill.

In the future, the number of industries or shops observed in this study will be increased. In particular, we have to survey the shops of shipbuilders that build huge steel ships. In such shops, they may use more highly automated and sophisticated apparatus, such as the CNC lathe. Furthermore, we have to survey the ability of such apparatus and tools. In this paper, we examined workers' behaviour from the viewpoint of work time. It contributes to a study of the effects of technological change from perspective of man. In the future, we would like to study the impact of technological change on work-not only from the perspective of man but also from that of machines. Moreover, the automation score invented by Bright (1958) will be useful to us.

References

Agnew, A., Forrester, P., Hassard, J. & Procter S. Deskilling and reskilling within the labor process: The case of computer integrated manufacturing. *International Journal of Production Economics*, 1997, 52, 317-324.

Attewell, P. The deskilling controversy. *Work and Occupations*, 1987, 14, 323-346.

Brannick, M.T. & Levene, E.L. *Job analysis: Methods, research, and applications for human resources management in the new millennium*. London: Sage, 2002.

Bright, J.R. Does automation raise skill requirements? *Harvard Business Review* 1958, 36, 85-98.

Cappelli, P. Are skill requirements rising? Evidence from production and clerical jobs. *Industrial and Labor Relations Review*, 1993, 46, 515-530.

Committee on National Needs in Maritime Technology. *National council, shipbuilding technology and education.* Washington DC: National Academy Press, 1996.

Cooke, F.L. The important role of the maintenance workface in technological change: A much neglected aspect. *Human Relations*, 2002, 55, 963-988.

Delong, D.W. *Lost knowledge: Confronting the threat of an aging workforce.* New York: Oxford University Press, 2004.

Dychtwald, K., Erickson, T.J. & Morison, R. *Workforce crisis: How to beat the coming shortage of skills and talent.* Boston, MA: Harvard Business School Press, 2006.

Form, W. On the degradation of skill. *Annual Review of Sociology*, 1987, 13, 29-47.

Hand, D.J. & Taylor, C.C. *Multivariate analysis of variance and repeated measures: A practical approach for behavioral scientists.* London: Chapman and Hall, 1987.

Iwasaki, Y., Taura, Y., Shiota, H., Hirabe, H. & Tookura, A. Study on the forming of hull plate by line heating method. *Mitsubishi Heavy Industry Technical Review*, 1975, 12, 51-59.

Kanawaty, G. Method study and the selection of jobs (6). In *Introduction to work study (4th. Ed.)*. Geneva: International Labor Office, 1992, 75-79.

Katz, R.L. Skills of an effective administrator. *Harvard Business Review*, 1955, 33, 33-42.

Koike, K. NUMMI and its prototype plant in Japan: A comparative study of human resource development at the workshop level. *Journal of the Japanese and International Economics*, 1998, 12, 49-74.

Leigh, D.E. & Gifford, K.D. Workplace transformation and worker upskilling: The perspective of individual workers. *Industrial Relations*, 1999, 38, 174-191.

Lewis, A. The deskilling thesis revised: On Peter Armstrong's defense of Braverman. *Sociological Review*, 1995, 43, 478-500.

Oliver, J.M. & Turton, J.R. Is there a shortage of skilled labour? *British Journal of Industrial Relations* 1982, 20, 195-200.

Olstein, M.A. Managing the coming brain drain. *Journal AWWA*, 2005, 97, 60-67.

Osterman, P. Skill, training, and work organization in American establishments. *Industrial Relations*, 1995, 34, 125-146.

Rolfe, H. In the name of progress? Skill and attitudes towards technological change. *New Technology, Work and Employment*, 1990, 5, 107-121.

Smith, R.N. Maintaining the nuclear skills base. *The Nuclear Engineer*, 2004, 45, 89-91.

Sokal, R.R. & Rohlf, F.J. Assumption of analysis of variance (13). In *Biometry*. New York: W. H. Freeman, 1995, 392-450.

Spenner, K.I. Deciphering Prometheus: Temporal change in the skill level of work. *American Sociological Review*, 1983, 48, 824-837.

Taylor, F.W. *The principles of scientific management.* New York: Dover, 1998.

Terai, K., Kurioka, T. & Takeuchi, H. Study on block assembling method of ship hull construction. *Journal of the Kansai Society of Naval Architects*, 1973, 147, 1-12.

Vallas, S.P. New technology, job content, and worker alienation. *Work and Occupations*, 1988, 15, 148-178.

Watson, D., Webb, R. & Johnson, S. Influence costs and the reporting of skill deficiency. *Human Relations*, 2006, 59, 37-59.

Zicklin, G. Numerical control machining and the issue of deskilling. *Work and Occupations*, 1987, 14, 452-466.

Appendix 1 Descriptive statistics on work time sorted by company, stage, and content of work (unit: s, not log translated)

Co. X

Operation	n	min.	max.	mean	median	SD
Processing	69	2	40	13.84	12	8.46
Assembly	123	5	555	84.43	78	71.29
Mount	188	2	164	31.71	21	33.71
Equipment	41	2	167	35.12	23	43.12
Stern	64	3	6840	674.80	34	1421.91
Machinery	111	3	586	91.84	47	118.83
Preparation						
Processing	69	2	118	27.67	20	25.93
Assembly	123	3	305	28.38	14	49.32
Mount	188	1	450	36.35	15	60.04
Equipment	41	2	450	26.20	12	69.10
Stern	64	2	2721	260.33	34.5	470.66
Machinery	111	5	920	158.62	85	189.50

Co. Y

Operation	n	min.	max.	mean	median	SD
Processing	150	4	298	52.40	37.5	49.78
Assembly	68	2	81	16.93	10	18.82
Mount	74	2	95	19.07	12.5	19.26
Equipment	26	6	207	47.50	39.5	44.05
Stern	NA	NA	NA	NA	NA	NA
Machinery	NA	NA	NA	NA	NA	NA
Preparation						
Processing	150	4	573	45.00	25	69.10
Assembly	68	2	610	44.82	20.5	81.78
Mount	74	2	1115	92.46	36	168.55
Equipment	26	4	517	48.15	18.5	101.00
Stern	NA	NA	NA	NA	NA	NA
Machinery	NA	NA	NA	NA	NA	NA

Appendix 2 Descriptive statistics on work time sorted by company, stage, and content of work (unit: s, log translated)

Co. X						
Operation						
Stage	n	min.	max.	mean	median	SD
Processing	69	0.69	3.69	2.42	2.48	0.69
Assembly	123	1.61	6.32	4.21	4.36	0.67
Mount	188	0.69	5.10	2.97	3.04	1.02
Equipment	41	0.69	5.12	2.95	3.14	1.16
Stern	64	1.10	8.83	4.22	3.53	2.24
Machinery	111	1.10	6.37	3.71	3.85	1.37
Preparation						
Processing	69	0.69	4.77	2.86	3.00	1.04
Assembly	123	1.10	5.72	2.72	2.64	0.98
Mount	188	0.00	6.11	2.78	2.71	1.25
Equipment	41	0.69	6.11	2.53	2.48	0.98
Stern	64	0.69	7.91	3.77	3.54	2.14
Machinery	111	1.61	6.82	4.37	4.44	1.27

Co. Y						
Operation						
Stage	n	min.	max.	mean	median	SD
Processing	150	1.39	5.70	3.60	3.62	0.86
Assembly	68	0.69	4.39	2.37	2.30	0.95
Mount	74	0.69	4.55	2.58	2.52	0.83
Equipment	26	1.79	5.33	3.53	3.68	0.85
Stern	NA	NA	NA	NA	NA	NA
Machinery	NA	NA	NA	NA	NA	NA
Preparation						
Processing	150	1.39	6.35	3.30	3.22	0.91
Assembly	68	0.69	6.41	3.02	3.02	1.24
Mount	74	0.69	7.02	3.60	3.58	1.36
Equipment	26	1.39	6.25	3.02	2.92	1.17
Stern	NA	NA	NA	NA	NA	NA
Machinery	NA	NA	NA	NA	NA	NA

Appendix 3 Descriptive statistics on work time sorted by company, FC, and content of work at Co. X (unit: s, not log translated; FC refers to the frequency of continuation)

Operation							Preparation				
FC	n	min.	max.	mean	median	SD	min.	max.	mean	median	SD
1	58	3	2825	106.60	29.5	372.51	1	1500	165.33	28	281.61
2	58	3	4215	126.24	31.5	550.62	2	855	51.31	21.5	115.57
3	58	3	3625	112.36	25.5	475.61	2	660	70.41	24	120.09
4	56	2	1900	77.98	22	261.88	2	750	82.20	19	147.78
5	48	2	2940	116.40	27	425.66	3	1020	60.38	18.5	154.39
6	43	3	3900	189.91	29	663.42	3	463	52.14	14	88.47
7	38	3	6840	217.63	19.5	1104.13	2	545	69.68	23.5	114.90
8	34	3	2240	121.65	26.5	383.08	2	360	47.74	18.5	74.25
9	30	3	480	71.47	25	114.28	2	680	65.27	19	131.62
10	23	2	1000	69.30	16	204.89	2	380	53.04	23	86.80
11	19	2	5370	315.26	23	1224.47	2	1070	101.84	15	248.14
12	19	2	270	45.58	21	65.16	3	245	54.42	17	68.09
13	14	3	295	79.86	26	99.04	3	240	52.64	47.5	59.12
14	11	7	709	116.64	40	202.45	3	407	72.09	15	126.25
15	10	7	241	76.80	37.5	79.18	2	367	49.50	13	112.25
16	10	6	420	114.90	64	136.14	3	61	27.30	25	21.75
17	7	7	190	78.86	81	61.73	5	75	28.57	16	28.83
18	7	5	242	81.00	83	83.20	7	825	172.86	21	297.26
19	7	7	112	66.43	68	44.93	5	790	139.29	32	288.18
20	6	24	163	72.50	62.5	48.83	5	896	161.83	13	359.89
21	6	4	1388	295.17	91.5	538.24	3	1190	215.00	25	477.73
22	6	26	235	106.33	82.5	79.53	2	2721	461.00	7.5	1107.19
23	5	7	968	235.80	86	410.97	3	717	148.00	7	318.09
24	4	8	107	59.25	61	41.45	5	20	13.50	14.5	7.68
25	4	7	78	44.00	45.5	33.93	3	12	5.50	3.5	4.36
26	4	31	89	58.50	57	26.35	5	11	6.75	5.5	2.87
27	4	5	48	32.00	37.5	18.89	3	45	19.00	14	19.85
28	4	4	90	45.00	43	35.79	14	29	18.75	16	6.90
29	2	6	41	23.50	23.5	24.75	3	45	24.00	24	29.70
30	1	53	53	53.00	53	NA	14	14	14.00	14	NA
31	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
32	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Appendix 4 Descriptive statistics on work time sorted by company, FC, and content of work at Co. Y (unit: s, not log translated; FC refers to the frequency of continuation)

Operation							Preparation				
FC	n	min.	max.	mean	median	SD	min.	max.	mean	median	SD
1	35	4	148	29.77	21	29.93	6	665	134.46	80	150.31
2	34	3	218	36.88	21.5	43.29	2	1115	74.97	28.5	190.92
3	30	2	207	31.80	18	39.42	3	136	34.27	23	32.43
4	29	2	208	37.90	29	42.46	2	192	37.66	18	46.41
5	29	5	298	49.90	30	64.53	4	553	66.41	20	144.27
6	25	3	95	27.52	15	25.01	4	218	36.08	18	53.23
7	22	2	120	40.50	31	32.25	2	573	60.91	26.5	118.70
8	18	2	146	28.28	19	33.77	3	95	29.94	22.5	26.58
9	13	2	188	38.54	25	50.95	5	81	31.38	17	27.98
10	11	3	45	17.36	10	15.36	4	359	56.73	17	102.34
11	10	3	59	23.30	19.5	20.23	5	95	37.20	32	29.41
12	7	5	159	55.29	40	56.18	8	180	44.29	18	61.67
13	7	14	166	59.43	43	52.27	10	33	15.29	10	8.56
14	7	10	107	42.14	16	42.41	15	46	25.86	20	12.35
15	6	10	87	29.00	20	28.93	25	211	75.83	33.5	76.00
16	5	7	40	18.00	15	13.40	8	50	21.40	17	16.77
17	4	5	110	48.25	39	47.39	10	311	90.25	20	147.35
18	4	13	58	32.50	29.5	20.92	13	62	27.25	17	23.26
19	3	10	35	18.67	11	14.15	4	79	33.67	18	39.88
20	3	24	67	43.00	38	21.93	8	75	44.33	50	33.86
21	3	6	60	33.00	33	27.00	10	37	27.33	35	15.04
22	2	14	50	32.00	32	25.46	2	21	11.50	11.5	13.44
23	2	13	42	27.50	27.5	20.51	18	22	20.00	20	2.83
24	1	155	155	155.00	155	NA	127	127	127.00	127	NA
25	1	68	68	68.00	68	NA	37	37	37.00	37	NA
26	1	75	75	75.00	75	NA	22	22	22.00	22	NA
27	1	5	5	5.00	5	NA	30	30	30.00	30	NA
28	1	61	61	61.00	61	NA	10	10	10.00	10	NA
29	1	16	16	16.00	16	NA	48	48	48.00	48	NA
30	1	260	260	260.00	260	NA	60	60	60.00	60	NA
31	1	45	45	45.00	45	NA	28	28	28.00	28	NA
32	1	75	75	75.00	75	NA	35	35	35.00	35	NA

Appendix 5 Descriptive statistics on work time sorted by company, FC, and content of work at Co. X (unit: s, log translated; FC refers to the frequency of continuation)

Operation							Preparation				
FC	n	min.	max.	mean	median	SD	min.	max.	mean	median	SD
1	58	1.10	7.95	3.38	3.38	1.43	0.00	7.31	3.75	3.33	1.74
2	58	1.10	8.35	3.48	3.45	1.29	0.69	6.75	3.11	3.07	1.22
3	58	1.10	8.20	3.38	3.24	1.27	0.69	6.49	3.26	3.18	1.42
4	56	0.69	7.55	3.17	3.09	1.26	0.69	6.62	3.24	2.94	1.50
5	48	0.69	7.99	3.41	3.30	1.38	1.10	6.93	3.08	2.92	1.23
6	43	1.10	8.27	3.64	3.37	1.38	1.10	6.14	2.96	2.64	1.38
7	38	1.10	8.83	3.20	2.97	1.48	0.69	6.30	3.30	3.16	1.38
8	34	1.10	7.71	3.46	3.28	1.41	0.69	5.89	2.97	2.91	1.37
9	30	1.10	6.17	3.28	3.22	1.46	0.69	6.52	3.04	2.94	1.54
10	23	0.69	6.91	2.93	2.77	1.39	0.69	5.94	3.05	3.14	1.43
11	19	0.69	8.59	3.34	3.14	1.69	0.69	6.98	3.13	2.71	1.61
12	19	0.69	5.60	3.04	3.04	1.31	1.10	5.50	3.21	2.83	1.35
13	14	1.10	5.69	3.57	3.26	1.40	1.10	5.48	3.47	3.86	1.11
14	11	1.95	6.56	3.94	3.69	1.25	1.10	6.01	3.09	2.71	1.57
15	10	1.95	5.48	3.77	3.60	1.19	0.69	5.91	2.64	2.54	1.46
16	10	1.79	6.04	3.89	4.03	1.55	1.10	4.11	2.88	3.11	1.08
17	7	1.95	5.25	3.99	4.39	1.09	1.61	4.32	2.91	2.77	1.02
18	7	1.61	5.49	3.72	4.42	1.44	1.95	6.72	3.90	3.04	1.73
19	7	1.95	4.72	3.82	4.22	1.12	1.61	6.67	3.54	3.47	1.68
20	6	3.18	5.09	4.11	4.13	0.65	1.61	6.80	3.10	2.39	1.98
21	6	1.39	7.24	4.37	4.51	1.92	1.10	7.08	3.48	3.22	1.95
22	6	3.26	5.46	4.41	4.41	0.81	0.69	7.91	2.94	2.01	2.55
23	5	1.95	6.88	4.21	4.45	1.82	1.10	6.58	2.60	1.95	2.28
24	4	2.08	4.67	3.74	4.09	1.15	1.61	3.00	2.45	2.60	0.67
25	4	1.95	4.36	3.42	3.69	1.11	1.10	2.48	1.52	1.24	0.66
26	4	3.43	4.49	3.99	4.01	0.48	1.61	2.40	1.85	1.70	0.37
27	4	1.61	3.87	3.18	3.62	1.06	1.10	3.81	2.37	2.28	1.33
28	4	1.39	4.50	3.34	3.74	1.36	2.64	3.37	2.89	2.77	0.33
29	2	1.79	3.71	2.75	2.75	1.36	1.10	3.81	2.45	2.45	1.91
30	1	3.97	3.97	3.97	3.97	NA	2.64	2.64	2.64	2.64	NA
31	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
32	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Appendix 6 Descriptive statistics on work time sorted by company, FC, and content of work at Co. Y (unit: s, log translated; FC refers to the frequency of continuation)

Operation							Preparation				
FC	n	min.	max.	mean	median	SD	min.	max.	mean	median	SD
1	35	1.39	5.00	2.94	3.04	1.00	1.79	6.50	4.42	4.38	1.04
2	34	1.10	5.38	3.07	3.07	1.08	0.69	7.02	3.25	3.35	1.35
3	30	0.69	5.33	3.01	2.89	0.95	1.10	4.91	3.12	3.14	0.96
4	29	0.69	5.34	3.08	3.37	1.15	0.69	5.26	3.04	2.89	1.11
5	29	1.61	5.70	3.39	3.40	0.99	1.39	6.32	3.12	3.00	1.21
6	25	1.10	4.55	2.93	2.71	0.92	1.39	5.38	2.98	2.89	1.05
7	22	0.69	4.79	3.35	3.43	0.97	0.69	6.35	3.34	3.28	1.20
8	18	0.69	4.98	2.83	2.94	1.05	1.10	4.55	3.02	3.11	0.93
9	13	0.69	5.24	2.93	3.22	1.35	1.61	4.39	3.04	2.83	0.96
10	11	1.10	3.81	2.47	2.30	0.96	1.39	5.88	3.22	2.83	1.21
11	10	1.10	4.08	2.70	2.89	1.09	1.61	4.55	3.27	3.46	0.95
12	7	1.61	5.07	3.41	3.69	1.31	2.08	5.19	3.20	2.89	1.08
13	7	2.64	5.11	3.76	3.76	0.90	2.30	3.50	2.62	2.30	0.46
14	7	2.30	4.67	3.31	2.77	0.98	2.71	3.83	3.16	3.00	0.45
15	6	2.30	4.47	3.08	2.98	0.76	3.22	5.35	3.96	3.51	0.89
16	5	1.95	3.69	2.68	2.71	0.71	2.08	3.91	2.85	2.83	0.70
17	4	1.61	4.70	3.32	3.49	1.37	2.30	5.74	3.48	2.93	1.57
18	4	2.56	4.06	3.31	3.30	0.70	2.56	4.13	3.09	2.83	0.71
19	3	2.30	3.56	2.75	2.40	0.70	1.39	4.37	2.88	2.89	1.49
20	3	3.18	4.20	3.67	3.64	0.51	2.08	4.32	3.44	3.91	1.19
21	3	1.79	4.09	3.13	3.50	1.19	2.30	3.61	3.16	3.56	0.74
22	2	2.64	3.91	3.28	3.28	0.90	0.69	3.04	1.87	1.87	1.66
23	2	2.56	3.74	3.15	3.15	0.83	2.89	3.09	2.99	2.99	0.14
24	1	5.04	5.04	5.04	5.04	NA	4.84	4.84	4.84	4.84	NA
25	1	4.22	4.22	4.22	4.22	NA	3.61	3.61	3.61	3.61	NA
26	1	4.32	4.32	4.32	4.32	NA	3.09	3.09	3.09	3.09	NA
27	1	1.61	1.61	1.61	1.61	NA	3.40	3.40	3.40	3.40	NA
28	1	4.11	4.11	4.11	4.11	NA	2.30	2.30	2.30	2.30	NA
29	1	2.77	2.77	2.77	2.77	NA	3.87	3.87	3.87	3.87	NA
30	1	5.56	5.56	5.56	5.56	NA	4.09	4.09	4.09	4.09	NA
31	1	3.81	3.81	3.81	3.81	NA	3.33	3.33	3.33	3.33	NA
32	1	4.32	4.32	4.32	4.32	NA	3.56	3.56	3.56	3.56	NA