Learning Effect of Interior Finishing and Building Services Works for Multi-Dwelling Complex Project

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Abstract -

In the construction industry, many individual trades have to work simultaneously. This creates many potential difficulties on the construction site, primarily in relation to efficiency loss and construction period extension. To improve efficiency, a new interior finishing system for dwelling was developed. By using the system, both interior finishing and building services system are well combined. It is a well-known fact that the repetitive nature of construction produces a learning effect, which reduces both the overall working period and labour man-hours utilized. However there is little learning data available that is specifically related to interior works. Therefore, using the developed method, an observation study was conducted in order to collect learning data in an 11 storey housing construction project. The analysis demonstrates that a typical learning effect was found in 11 recorded repetitions.

Keywords
learning curve effect, labour productivity, interior finishing work, building services work, multi-dwelling complex

1 Introduction

This study aims to integrate interior finishing works and building services works in a Multi-dwelling complex construction. An interior finishing work consists of various trades' activities and they are carried out simultaneously. This causes interferences among trades, which results in low productivity in a project. To solve the problem a new interior construction method has been developed in which a carpenter carries out most of the interior finishing as well as building services works such as electric wiring and plumbing. The productivity of the interior finishing works has been reported in a previous paper [1].

In the construction planning for a building project, the manpower plan is carried out by considering learning or experience curve effect of labours. There are many studies to confirm the learning curve effect [2][3]. However, such studies are lacking for Multi-dwelling complex interior construction. This paper discusses learning or experience curve effect on interior finishing works by repetition (the proposed system should encompasses both interior finishing and building services, but due to circumstances, this study is limited to only interior finishing). To obtain man-hours data of interior finishing workers, actual projects were observed by using a newly prepared activity recording sheet.

2 Objective and Scope

The authors developed an interior finishing and building services system, called "panel system", for Multi-dwelling complex. The purpose of the system is to reduce manpower and construction time in an interior finishing work, and is explained in 3.3.1 in detail. This paper studies the system in an actual interior finishing work. Basic data such as man-hours for each activity, work process, and construction time are recorded and analyzed. Through the study, basic data to improve the construction system and planning of future project were obtained. Furthermore, we identified reduction of construction time and man-hours by learning curve effect as a sequel to repetition of work.

3 Observation Items and Methods

3.1 Observation Items

The authors conducted observations on interior finishing and worked on a Multi-dwelling complex construction project. The observation items are:

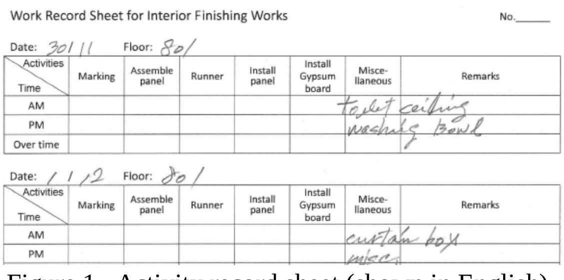
(1) Problems in the “panel system” during construction,
(2) Processes in interior finishing work,
(3) Changes in construction time and man-hours of each activity in each floor.

3.2 Observation methods

3.2.1 Man-hours

To obtain accurate data during the whole construction period, the authors prepared a specially designed activity recording sheet which records dates, activities, and locations every day. The recording sheet is not comparable to time study in accuracy, but is useful to measure man-hours for a long period of entire project term. In the sheet, one day is divided into three time zones; morning, afternoon, and overtime; the main activities in each time zone are recorded. The activity in each time zone is to be selected from several predefined ones, by drawing a circle in the cell below the selected activity’s label; activities not among the predefined ones are to be written in a cell under the label “Miscellaneous”. Each sheet holds the record of a week, which consists of six days (i.e. excluding Sunday).

In our study, recordings were performed by a selected worker during rest in each time zone. At the start of the observation period, the authors had several meetings with supervisors, site engineers, foremen from sub-contractors, and workers to initiate them to the objective and significance of the observation. An appropriate worker was selected after the meetings. The selected worker recorded his activities during the entire construction period; this did not burden him since each recording took less than a minute. The authors visited the project site to copy the records once a week. At that time, problems on recording activities were discussed. Measures were taken immediately for the resolvable problems. The records were taken from the 2nd to the 11th floor inclusively. Figure 1 shows an example of a completed activity recording sheet.



Work Record Sheet for Interior Finishing Works No.______

Date: 30/11 Floor: 801

Activities / Time	Marking	Assemble panel	Runner	Install panel	Install Gypsum board	Misce-llaneous	Remarks
AM						toilet ceiling	
PM						washing Bowl	
Over time							

Date: 1/12 Floor: 801

Activities / Time	Marking	Assemble panel	Runner	Install panel	Install Gypsum board	Misce-llaneous	Remarks
AM						curtain box	
PM						misc	

Figure 1. Activity record sheet (shown in English)

3.2.2 Schedule

The project schedule was extracted from the records in the activity recording sheet. The dates of the activity start and end were read from the activity record, and the data was processed by using scheduling software.

3.3 Subject of the observation

3.3.1 Outline of the construction method

The construction method was developed for the purpose of improving construction productivity and building services equipment maintenance works. To achieve the purpose, dwelling interior finishing works and building services works were incorporated properly. The basic element of the system is a gypsum board panel combined with wooden studs (in short “panel”). The panel is used as an element of partitions in a dwelling. The dimensions of the gypsum board are: 12.5mm thickness, 910mm width, and slab height. Wooden studs are 40mm × 35mm section.

Figure 2 shows a standard panel. After installing backing frames, panels are installed, and then electric wiring and plumbing works, finally folded gypsum boards are installed. Based on the panel system, other interior finishing and building services works such as water supply, sewage, and electric wiring works are integrated. By integrating the construction method and introducing multi-skilled worker, idle among work trades and work process are eliminated, which are common problems in most construction projects. Hence, work efficiency is improved.

Figure 3 shows a corridor partition which is a basic usage of panels. This type of plan is the most popular for current Multi-dwelling complexes in Japan. As shown in the figure, main building services such as water supply pipes and electric wires are installed in the ceiling cavity which allows simplification on piping and wiring to each room. Although the system makes the distances of wiring and plumbing longer than conventional methods, it also makes work easier.

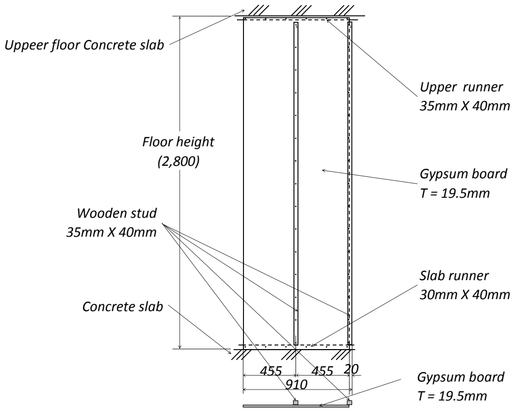


Figure 2. Standard gypsum board panel

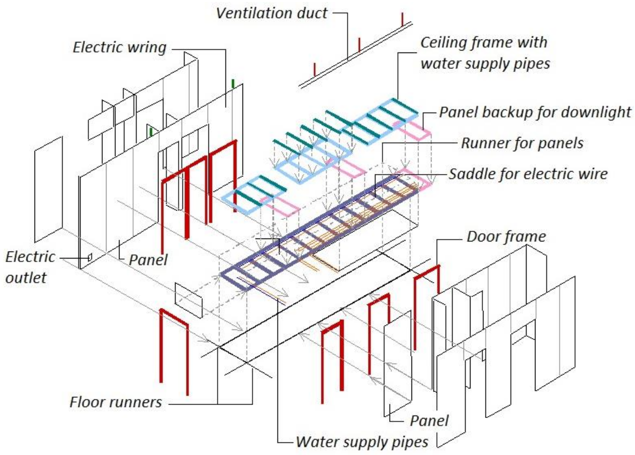


Figure 3. The panel interior finishing system

The system simplifies interior finishing and building services works for Multi-dwelling complexes. In the development of the method, the authors carried out two mockup experiments; through the experiments, technical problems were identified and solved before the system's actual deployment.

3.3.2 Outline of the construction project

Table 1 shows the outline of the project to which the panel system was applied. The project is a middle height Multi-dwelling complex, located in a housing area. Before commencement of the project, the authors tried to introduce the developed panel system. However, due to contract conditions and maintenance of building services equipment, the building services works part of the panel system cannot be applied, and is left out of this study.

Table 1 Outline of the project

Item	Description
Building use	Multi-dwelling complex
Location	Chiba, Japan
Structure	Reinforeced concrete
Storey	Sub-structure: 14 storey, Basement: 1 storey
N. of dwellings	137
Building height	40.7 m
Site area	14,892 m^2
Building area	1,673 m^2
Total floor area	16,340 m^2
Average area of a dwelling	93 m^2
Interior finishing method	Timber/steel backing frame & gypsum board

4 Results of the observation

4.1 Analysis of actual schedule

4.1.1 Actual schedule

For the observation, a typical dwelling was selected and activities were recorded from the 2nd floor to the 11th floor, using the activity recording sheet. The actual schedule was also recorded using this sheet. The selected dwelling was located at a gable-end side. The object of the observation was a 93m^2 floor area consisting of three bed rooms, a living room, a dining room, a kitchen, and a

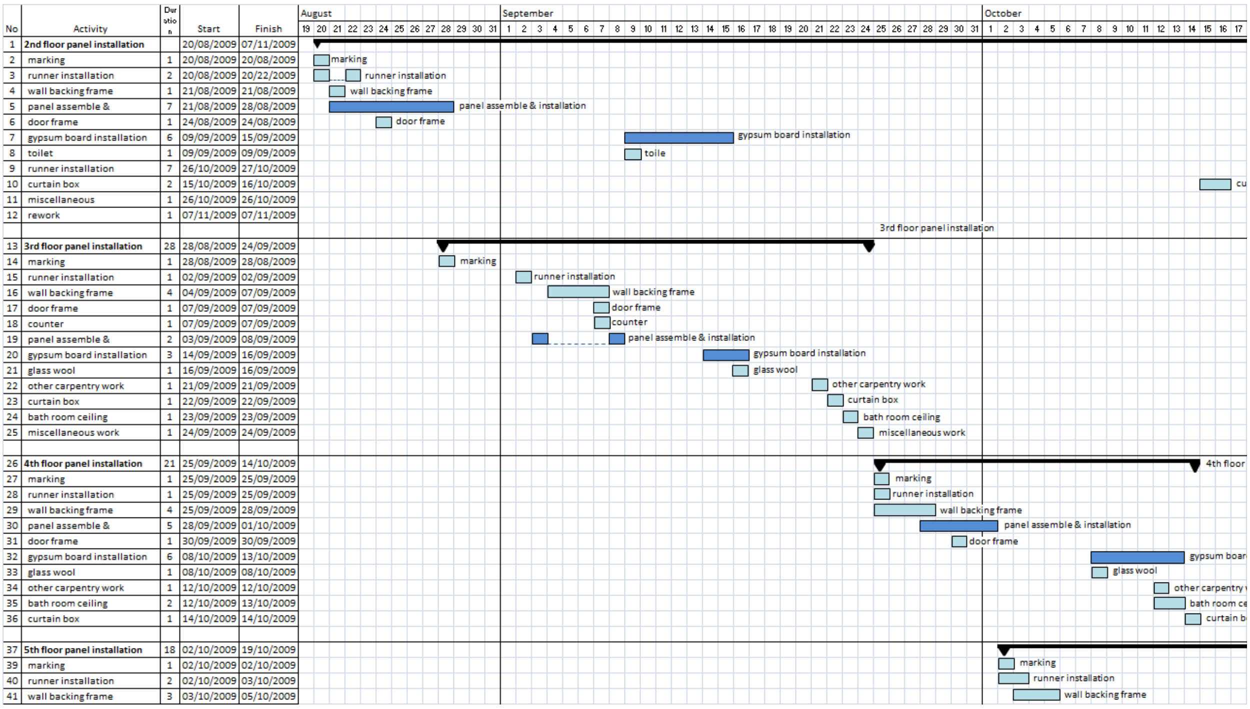


Figure 4. Actual schedule of each activity

toilet/bathroom. The room setups from the 2nd to the 13th floor are the same, with the exception of special experiments at the 12th and 13th floor. Therefore, activity records were taken at 2nd to 11th floor. The work repetition was ten times. The numbers of repetition is enough to analyze learning effect.

Fig.4 shows an actual schedule drawn with scheduling software using source data obtained from the activity recording sheet. In Figure 4, the actual schedule for each activity is represented from top to bottom. The black bar with triangles at both edges shows one floor's schedule from start to finish; it indicates the whole period of each floor including non-working days, that is, in "calendar days". Hence, the entire construction starts from the marking for the 2nd floor until the marking for completion of 13th floor, giving a total of 184 days, with 109 clear days. Works on the 13th floor finished on 18th February 2009. The activities of the 2nd floor activities are shown at the top of the chart. Most of the activities were completed in August and September. However, curtain box, counter, and several other activities were carried out in October and November 2008. As a result, whole construction period became 63 calendar days and clear working day was 17 days. There is a big difference between the two.

4.1.2 Change of construction days for each floor

Figure 5 shows calendar days and clear days for each floor from the 2nd to the 11th floor. As shown in Figure 5, the calendar days for each floor's construction were reduced according to the construction progress. They changed as follows, 63 days at the 2nd floor, 20 days at the 3rd floor, 15 days at the 4th floor, and 12 days at the 6th floor. However, each floor construction days increased from 14 to 26 days from the 7th to the 10th floor. From the 9th to the 10th floor, the calendar days include the Japanese New Year holidays. Hence, the calendar days for the 9th and 10th floor increased.

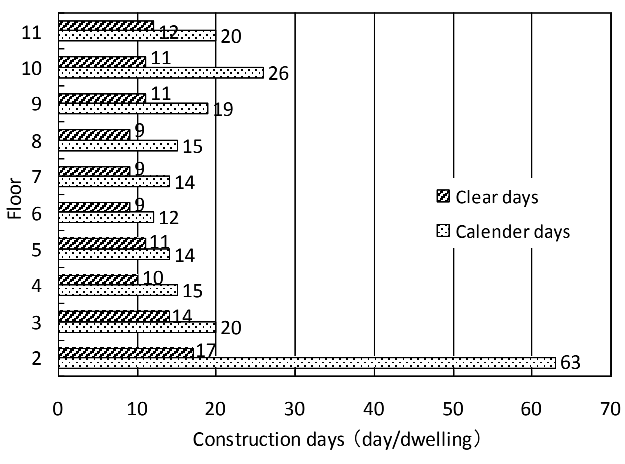


Figure 5. Actual schedule of each floor

On the other hand, clear days for each floor reduced form the 2nd floor to the 8th floor according to the construction progress. For this reason, we consider that learning curve effect has occurred, being caused by repetition of same activities. However, the clear days for each floor increased after the 9th floor. Again, this is due to the holidays.

4.1.3 Learning effect of construction days

In this section, learning curves are calculated based on the above data. Generally, learning effect is represented by equation (1).

$$A_c = t_1\, x^{-n} \qquad (1)$$

A_c: cumulative average days (day)

t_1: number of days for the first repetition (2nd floor)

x: numbers of repetition (floor)

n: learning coefficient (slope of a line when plot on the logarithm graph)

Learning rate is a decreasing rate of time or man-hours. It represents decreased rate of time when repetition becomes doubled (from the initial value). The learning rate is represented by equation (2).

$$P = (1/2)^{\,n} \qquad (2)$$

P: learning rate
n: learning coefficient

According to past researches, the learning rate for building works are reported as almost 0.75 – 0.95. Figure 6 shows the learning curves for each floor construction days. As shown in the graph both calendar days and the clear days for each floor decrease floor by floor. The learning rates are calculated by using equation (2) as follows;

The learning rate for calendar days: 0.71,

The learning rate for clear days: 0.86.

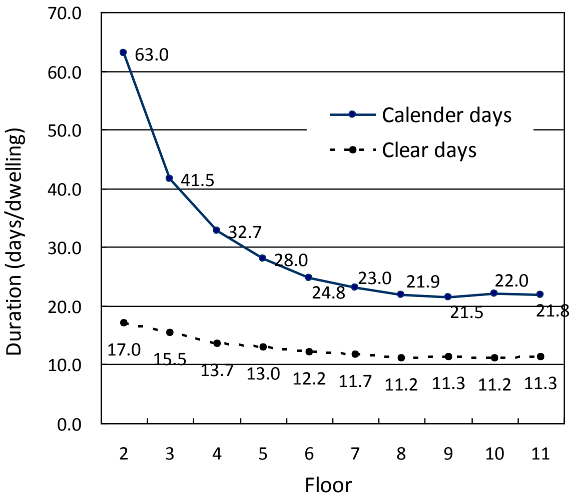


Figure 6. Learning curve effect of actual schedule

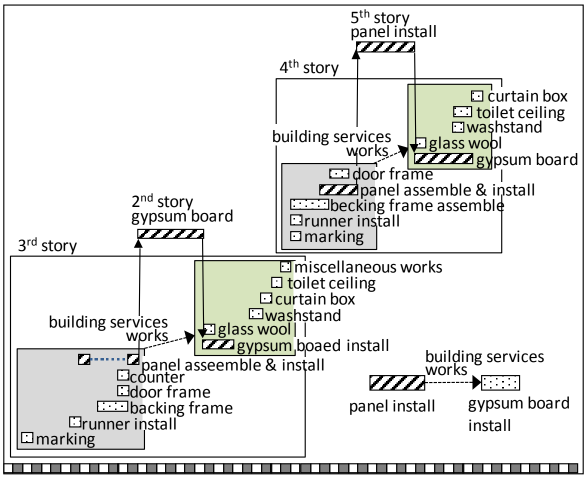


Figure 7. Process model of the panel system

We can recognize a certain pattern in the work progress shown in Figure 4. As seen in the graph the work begins with marking in each floor, then panel assembling and installation, and door frame, counter, etc continue. There are some idle days after these activities. During these days the carpenters did their works at lower or upper floor; meanwhile, electricians did electric wiring, and plumbers did water supply piping in walls and ceilings. After these works have been done carpenter carried out the latter half of their activities.

The primary purpose of the panel system is to reduce this idle time between activities by introducing multi-skilled workers. However, multi-skilled workers were not introduced, thus the remaining works were done in the conventional way. In this project the idle days were filled-in that carpenters did their work at other floors.

Figure 7 shows the process model of these series of activities. The carpenter's work schedule on a specific location is often interrupted by the need for other preceding trades to be completed his work scope before he can complete.

4.2 Man-hours analysis

4.2.1 Man-hour for each activity

The average value of total man-hours for each floor is 10.53 man-day/dwelling. The mean values of each activity from the 2nd to the 11th floor are shown in Figure 8. The largest man-hours activity is gypsum board and its value is 2.35 man-day/dwelling. The next largest is backing frame, with a value of 1.58 man-day/dwelling, followed by panel assemble and install, with 1.56 man-hours/dwelling.

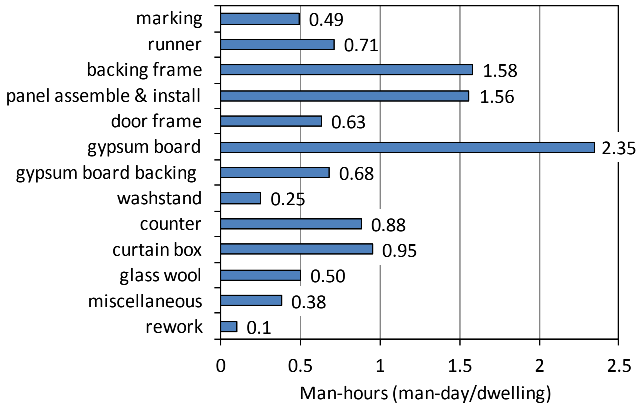


Figure 8. Man-hours of each activity

The main reasons of large man-hours for gypsum board are as follows.

(1) As the activity was carried out after panels are installed, that there were not enough space to treat large size gypsum boards.

(2) There were many on-site processing works.

4.2.2 Change of man-hours

Man-hours data collected by the activity recording sheet is summed up and calculated to obtain learning curve effect data. Figure 9 shows the change of total man-hours for each floor. The "individual man-hours" in the graph means the man-hours for each floor, and "cumulative average man-hours" means cumulative means for each floor from the 2nd to the 11th. As shown in the graph the man-hours for each floor decreased according to increase of floor. The cumulative average man-hours are noticeable in man-hours decrease. It is considered a result of learning effect. Generally, the cumulative average man-hours are suitable for calculating the learning curve effect. The actual man-hours change was explained in 4.2.1, thus it is omitted in this section. As mentioned above, there is a learning effect in total man-hours for each floor.

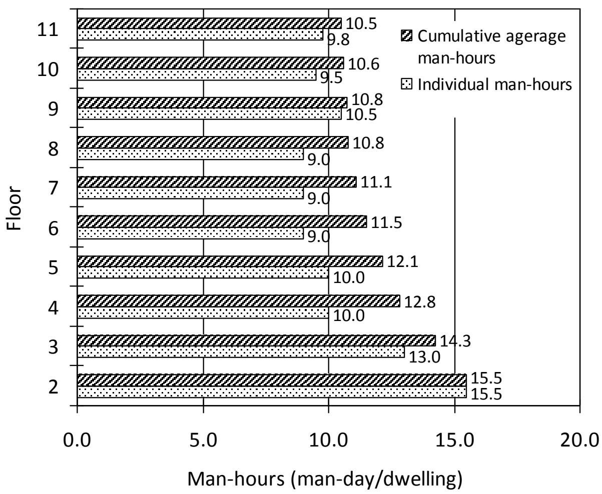


Figure 9. Change in total man-hours for each floor

4.2.3 Learning effect of total man-hours for each floor

Figure 10 is the graph showing learning curve of total man-hours for each floor for 2^{nd} – 11^{th} floor.

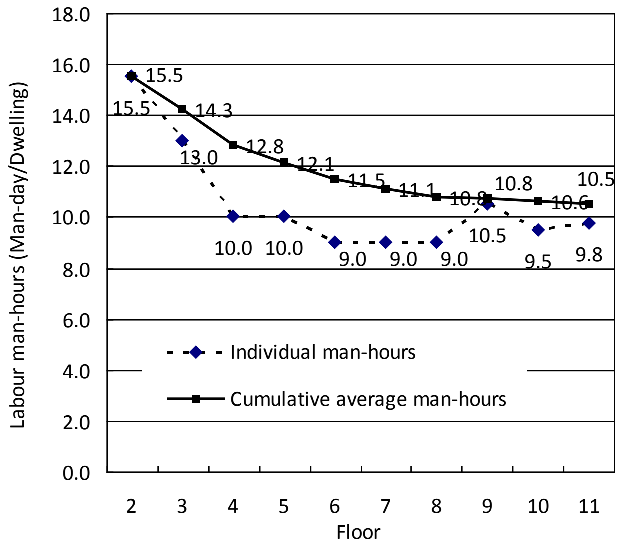


Figure 10. Learning curve for total man-hours per floor

In the graph both cumulative average man-hours and individual man-hours are displayed. Watching the change in the cumulative average man-hours in the graph, the learning effect can be implied. The learning rate is calculated as 0.86.

Theoretically, the learning effect should continue without limit. However, the man-hours reduction converged to a limit, stabilizing at almost 10 times repetitions. Some part studies' assessment on learning curve effect was derived from 10 times repetition of the same task [4]. As calculated above the learning effect for the panel construction is 0.86 learning rate, which means that the cumulative average man-hours for second repetition is 86 percent to the initial man-hours. As stated in section 4.1.3, previous studies on building construction works shows that the learning rate of many of the construction works are 0.75 – 0.95. Table 3 shows the learning rate for building works publicized by United Nations Committee on Housing, Building, and Planning [5]. The panel system is a finishing work, and it is comparable to category III in Table 3. Therefore, the learning rate is around 0.85, calculated value is 0.86 which is almost equivalent to the value in Table 3.

Table 3. Learning rate for building construction

Category	Description	Learning rate
I	Entire structure of ordinary complexity such as high-rise office building and tract housing	0.95
II	Individual construction elements requiring many operations to complete such as carpentry, electrical work, plumbing, erection and fastening of structural units, concreting.	0.90
III	Individual construction elements requiring few operations to complete such as masonry, floor and ceiling tile, painting.	0.85
IV	Construction elements requiring new operations and on assembly-line such as field fabrication of trusses, formwork panels and bar bending.	0.80
V	Plant manufacture of building elements such as doors, windows, kitchen cabinets, and prefabricated concrete panels.	0.90-0.95

4.2.4 Learning effect of each activity

Having confirmed the learning effect for total man-hours of each floor in the previous section, the learning effect for each activity is calculated here. However, the data was recorded by a worker who actually worked and at the same time recorded data at intervals of half a day. Therefore, highly accurate man-hours data cannot be expected for further analysis. Hence we analyzed only to confirm whether each activity was under the learning effect.

In the analysis activities such as “miscellaneous”, “rework” were eliminated because these activities are not recurrent. Figure 11 shows the relationship between floor (repetition) and cumulative average man-hours for each activity. Decrement of cumulative average man-hours can be distinguished from this graph. They are backing frame, gypsum board, curtain box, and counter. However, it is difficult to distinguish if an activity is under the learning effect if it has man-hours less than 1.00 man-days.

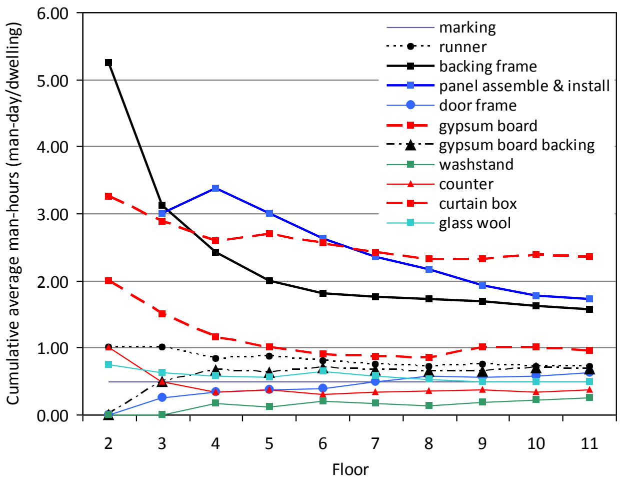


Figure 11. Change in cumulative average man-hours for each activity

For backing frame, gypsum board, the man-hours curve show typical learning curve. Conversely, man-hours are decreased in such activities as panel assemble and install, and door frame. Furthermore, man-hours of panel assemble and install increased rapidly as 0.75 man-days/dwelling at the 2nd floor to 3.00 man-days/dwelling at the 3rd floor. As a result, the learning curve has a convex shape. We assumed that some data was missing in activity "panel assemble and install" at the 2nd - 3rd floor. In Figure 11, learning curves for small man-hours such as runner, washstand, and glass wool are difficult to distinguish.

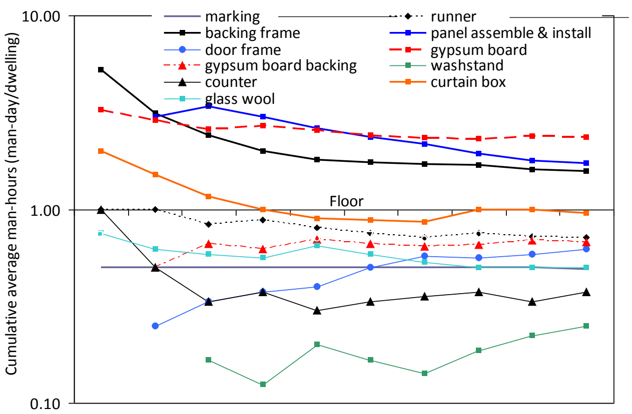


Fig.12. Change in cumulative average man-hours for each activity

Table 4. Learning effect in each activity

Work process	Learning rate	Remarks
marking	—	Man-hours are constant from 2nd to 10th floor
runner	0.86	—
backing frame	0.71	A remarkable learning effect is recognized.
panel assemble & install	—	Missing of 2nd floor data
door frame	—	—
gypsum board install	0.94	—
ceiling backing board	—	—
washstand	—	—
counter	—	—
curtain box	0.74	The learning curve effect is calculated with data from 2nd to 8th floor.
glass wool	0.89	Man-hours increased drastically at 6ht floor.

From the graph, we observe that runner and glass wool activities show the learning effect. It is difficult to confirm the learning effect for counter because its man-hours are too small to distinguish. Thus, we plotted it in a graph of logarithmically scaled vertical axis in Figure 12. A gradual decrease is observed from the 2nd to the 4th floor, while an increase is observed at the 5th floor. Due to this large fluctuation of man-hours, we consider that counter did not have the learning effect. Obviously, man-hours of washstand increased by repetition. The possible causes are mistakes in record or man-hour increased in actual fact.

Based on the analysis, the learning rates for each activity are calculated and shown in Table 4. In the table, learning rates are not shown where the learning effect is not observed. Although learning effect is confirmed on total man-hours, some activities did not have learning effect. Figure 11 and 12 shows that the man-hours of each activity fluctuated differently. The learning effect should appear in total man-hours when large man-hours activity has learning effect. However, this is not the case here.

5. Summary

The authors have developed the panel system to integrate interior finishing and building services works which was applied to a Multi-dwelling complex. Actual application was limited to only carpentry work, excluding building services works such as electricity and plumbing. Through the application we obtained construction system improvement data for future projects. At the same time man-hours data was recorded of the interior finishing work. The summary of the study is as follows.

(1) Construction time for each floor reduced according to increase in floor which shows learning effect. The learning rate is 0.86.

(2) Total man-hours for each floor also show learning curve effect and its learning rate is 0.86. The result of the observation is in good agreement with past studies.

(3) Some activities show learning effect, but some do not. The learning rates were calculated for each activity in which activities learning effects were confirmed.

(4) Average man-hours for each activity are calculated. Man-hours of "gypsum board", "backing frame", and "panel assemble and install" are large.

Collected data and information were used to improve the system and also stored for future projects.

Acknowledgement

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