Construction performance comparison between conventional and industrialised building systems in Malaysia

M.R. Abdul Kadir
Housing Research Centre, Faculty of Engineering, Universiti Putra Malaysia, Serdang, Malaysia
W.P. Lee
Department of Built Environment, Faculty of Engineering and Science, Universiti Tunku Abdul Rahman, Kuala Lumpur, Malaysia
M.S. Jaafar
Department of Civil Engineering, Faculty of Engineering, Universiti Putra Malaysia, Serdang, Malaysia
S.M. Sapuan
Department of Mechanical and Manufacturing Engineering, Faculty of Engineering, Universiti Putra Malaysia, Serdang, Malaysia, and
A.A.A. Ali
Housing Research Centre, Faculty of Engineering, Universiti Putra Malaysia, Serdang, Malaysia

Abstract

Purpose – Labour usage represents one of the critical elements in the Malaysia construction industry due to severe shortage of local workers. This paper aims to present a construction performance comparison between conventional building systems and industrialised building systems (IBS).

Design/methodology/approach – Data were obtained from 100 residential projects through a questionnaire survey in 2005. A total of 100 respondents participated in this study.

Findings – Analysis of variance (ANOVA) results indicated that the actual labour productivity comparison between conventional building system and IBS was significantly different. Further, the comparison of crew size indicated that the conventional building system of 22 workers was significantly different from the IBS of 18 workers. Similarly, the cycle time of 17 days per house for conventional building system was found to be significantly different from the IBS of four days. However, the conventional building system was found to be insignificantly different from the IBS in term of structural construction cost.

Originality/value – The results acquired from this study could be used by project planners for estimating labour input, control costs and project scheduling. Additionally, they could be used to determine the most appropriate structural building system for executing a construction project at the conceptual stage.

Keywords Labour efficiency, Construction systems, Malaysia

Paper type Research paper

The authors would like to acknowledge the help provided by Construction Industry Development Board, Malaysia (CIDB) and Intensification of Research in Priority Areas, (IRPA) of the 7th Malaysia Plan for funding this study.

Structural Survey
Vol. 24 No. 5, 2006
pp. 412-424

0263-080X
DOI 10.1108/02630800610712004

Introduction

In the 7th Malaysia Plan, the country planned to construct about 800,000 units of houses for its population. 585,000 units (or 73.1 per cent) were planned for low and low medium cost houses. Nevertheless, the achievements are somewhat disappointing with only 20 per cent completed houses in this category despite numerous incentives and promotions to encourage housing developers to invest in such housing category (Ismail, 2001).

With the announcement of the 8th Malaysia Plan, the country continues to embark on the development of affordable and sustainable low and medium cost housing. However, the country is facing an uphill task to accomplish the target of 600,000-800,000 houses during this period because the conventional building system currently being practiced by the construction industry is unable to cope with the huge demand. Therefore, the industry must find an alternative solution such as the industrialised building system (IBS) which has immense inherent advantages in term of productivity, indoor quality, durability and cost (IEM, 2001).

In essence, the demand for construction labour usage varies as the project progresses from structural work (including basement construction), architectural and finishing work and mechanical and electrical (M&E) work. Furthermore, the proportion of foreign to local workers also differs considerably through these stages because of different skills required to accomplish the task. The distribution of total labour and the proportion of foreign labour in these stages of building work are shown in Table I. Albeit, the statistics presented in Table I are cited from the Singapore construction industry, the paradigm is similar to Malaysia construction industry as both countries' workers are shying away from the construction industry. At the end of 1991, the total Singapore construction workforce was about 120,000, of which over 80,000 were foreign workers. The biggest block of foreign workers are Malaysian who constitute 34 per cent of the total number of construction workers, followed by Thais (25 per cent), Bangladeshis (10 per cent), Indians, Sri Lankans, Myanmarese, and those from North Asian countries such as South Korea, China, and Taiwan (Lim and Alum, 1995). Whereas, in Malaysia, the number of legal foreign workers for the construction sector were 19.8 per cent out of a total of 1.36 million in July 2004 (*The STARS*, 2004). Out of this figure, 66.5 per cent were from Indonesia, followed by Nepal (9.2 per cent), Bangladesh (8 per cent), India (4.5 per cent) and Myanmar (4.2 per cent).

Table I. Usage of workers and potential for productivity improvement in building work

Work type (1)	Usage of workers (%) (2)	Usage of foreign workers (%) (3)	Potential for productivity improvement (4)	Skills replaceable (5)	
Structural	50	80-85	High	Craft	Assembly
Finishing	30-35	50-60	Medium	More craft and less assembly	Less craft and more assembly
Mechanical and electrical	15-20	30	Low	Assembly	Assembly

Source: CIDB (1992)

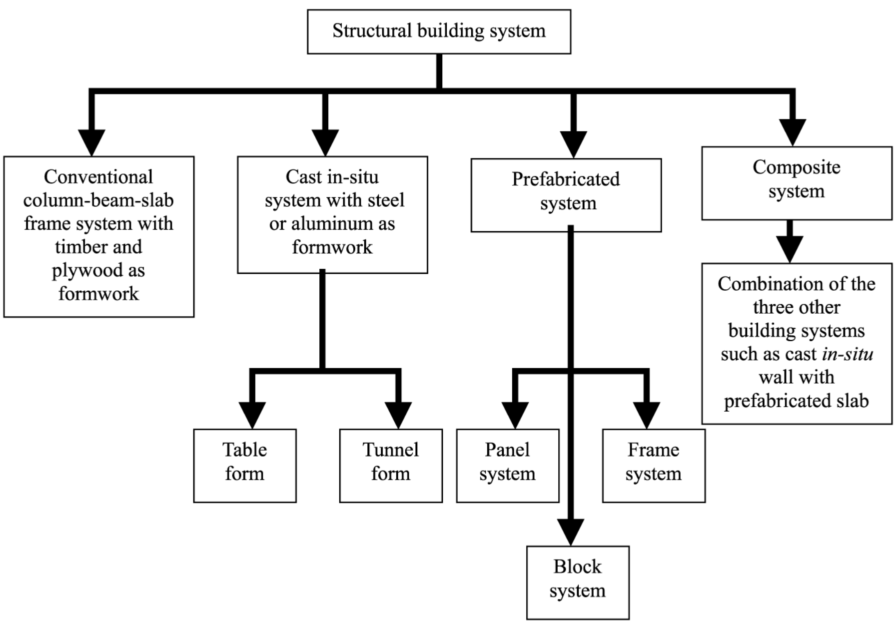
Types of building system

According to the Badir-Razali building system classification (Badir *et al.*, 1998) there are four main categories:

1. conventional building system;
2. cast *in-situ* formwork system – table or tunnel formwork;
3. prefabricated system; and
4. composite system as shown in Figure 1.

The last three building systems are termed as IBS.

Junid (1986) expounded that an IBS in the construction industry includes the industrialised process by which components of a building are conceived, planned, fabricated, transported and erected on site. The system includes a balanced combination between the software and hardware components. The software elements include system design, which is a complex process of studying the requirement of the end-user, market analysis, development of standardised components, establishment of manufacturing and assembly layout and process, allocation of resources and materials and definition of a building designer conceptual framework. The software elements provide a prerequisite to create the conducive environment for industrialisation to expand. On the other hand, the hardware elements are categorised into three major groups. These include frame or post and beam systems, panel system, and box system. The frame structures are defined as those structures that carry the loads through their beams and girders to columns and to the ground whilst in panel systems, loads are



Source: Badir *et al.* (1998)

Figure 1.
Type of building systems in Malaysia

distributed through large floor and wall panels. The box systems include those systems that employ three-dimensional modules (or boxes) for fabrication of habitable units capable of withstanding load from various directions due to their internal stability.

The conventional building system is divided into two major components. The first component is the structural system, which includes cast *in-situ* column-beam-slab frames. These frames are constructed through four operations, namely, erection of timber formwork and scaffolding, erection of steel bar, pouring of fresh concrete into form and dismantling of formwork and scaffolding. These operations are labour intensive, tedious and require a lot of on-site coordination. The second component consists of brick and plaster as the non-structural infill material.

Cast *in-situ* building systems utilise lightweight prefabricated formwork made of steel, fibreglass or aluminium in order to replace the existing conventional timber formwork. The method is suitable for large numbers of housing units that require repetitive utilisation of formwork. The formwork can be reused as many times as possible with minimal wastage. Careful planning of cast *in-situ* work can improve productivity, speed, and total cost (Ismail, 2001).

Fully prefabricated building systems can be classified into two main categories, namely on-site prefabricated and off-site prefabricated (factory produced). On-site prefabricated method involves casting structural building elements within site before erecting to actual location. On-site precasting provides several advantages over cast *in-situ* construction. These include mass production of units, cost and time reduction and improved quality of work (CIBD, 1992). Off-site prefabricated method involves transferring building operations from site to factory. Prefabrication allows a component to be built whenever convenient, so long as it is delivered on time.

The composite construction method involves casting some elements in the factory while others are cast on site. Types of precast elements usually produced are floor slabs, infilled wall, bathrooms, and staircase. These elements are placed for incorporation into main units, column and beams, which are usually, cast *in-situ*.

Research objective

Having described the types of building systems, it is important to statistically compare the conventional building system and IBS in term of labour productivity, construction structural cost, crew size and cycle time. The focus of this study is on structural work because the demand for labour in structural work is high and employs more foreign workers. It therefore has the highest potential for productivity improvement and reduction in foreign workers. The major operations (in terms of manpower usage) involved in the structural works are formwork carpentry, steel reinforcement and concreting. Among these operations, formwork carpentry requires the most skill while reinforcement work requires skill in taking off and scheduling; bending is quite mechanised and steel fixing is an assembly skill for which unskilled foreign workers can be trained. On the other hand, the concrete pouring work skill is simple and easy to acquire. The potential areas of productivity improvement in these operations are shown in Table II.

Benefits to industry practitioners

Labour usage represents one of the critical elements in the Malaysia construction industry due to severe shortage of local workers. The industry relies heavily on foreign workers from Indonesia, Bangladesh, Thailand and Vietnam which can precipitate economic and social problems. The labour productivity, structural cost, crew size, cycle time and workers' daily salary obtained from this study could be used by project planners for estimating labour input, control cost and project scheduling. Additionally, they could be used by policy makers to determine the most appropriate structural building system for executing a construction project at the conceptual stage.

Research methodology

The data for this paper were obtained through questionnaires mailed to respondents involved in residential projects. A total of 100 respondents responded to this study, hence providing key information on 100 projects. The respondents were project managers, project engineers and quantity surveyors working with contractors, consultants and developers and involved directly in the planning, supervision and monitoring of residential projects. They were asked to provide the pertinent project characteristics such as cost of structural work, number of houses, type of structural building system, workers' daily wage, average crew size for carpenter, barbender, concreter, crane operator and construction time required to accomplish the structural element of one house.

The reason for focusing on residential projects is to discount the possible variation due to irregular structural layout plan if other types of projects such hostels, universities and schools are considered. Moreover, residential projects have typical structural layout plans and are repetitive, even though minor variation might occur. This makes direct comparison between building systems more representative and unbiased.

Project characteristics of the actual residential projects

This section examines the actual residential projects' characteristics quoted by the respondents which includes distribution of structural building system, type of residential project and project construction cost. All the project details were categorised according to seven major structural building system, namely conventional building system, cast *in-situ* table form system, cast *in-situ* tunnel form system, full precast concrete system (precast concrete wall with precast half slab), composite system (precast concrete wall with cast *in-situ* slab system), block system and timber framing system.

Table II. Productivity improvement for structural work

Operation (1)	Improvement/alternative (2)	Productivity impact (3)
Formwork fixing	Precast structural components (especially beams), flat slabs and less on-site cast beams or no beams	High
Steel reinforcement	Prefabricated reinforcement	Medium
Concrete pouring	Precast slabs	Low

Source: CIDB (1992)

Out of 100 residential projects, 55 projects (55 per cent) used conventional building system as the main structural system followed by cast *in-situ* table form system with 16 projects (16 per cent), cast *in-situ* tunnel form system with nine projects (9 per cent), full precast concrete system (precast concrete wall with precast half slab) with 15 projects (15 per cent), composite system (precast concrete wall with cast *in-situ* slab system) with 3 projects (3 per cent), block system and timber framing system with one project respectively as shown in Table III.

Table IV depicts the distribution of residential projects in relation to total project construction cost. It can be observed that the majority of projects have average houses of 570 per project indicated that the developers preferred to build more houses in a single project to take advantage of economies of scale.

All the projects were also classified according to type of residential project as shown in Table V. It was found that the conventional building system was used in all types of residential projects. This was attributed to the flexibility of the system to suit all types of construction work. The timber and plywood used in this system can be easily cut, bent and modified to cater for any irregular shape of structural elements. On the other hand, the cast *in-situ* table and tunnel form systems were only used in apartment (21 projects) and condominium (four projects). The steel moulds used in these systems are expensive, and can be only used if large numbers of houses were to be constructed to

Structural building system (1)	Frequency (2)	Percentage (3)	Cumulative percentage (4)
Conventional	55	55	55
Cast *in-situ* table form	16	16	71
Cast *in-situ* tunnel form	9	9	80
Precast concrete wall and precast half slab system (full precast system)	15	15	95
Precast concrete wall and cast *in-situ* slab (composite system)	3	3	98
Block system	1	1	99
Timber framing system	1	1	100

Table III. Frequency distribution on the type of structural building systems

Total project construction cost (in RM million) (1)	Frequency (2)	Percentage (3)	Cumulative percentage (4)	Average number of houses per project (5)
< 6	17	17	17	42
6-10	15	15	32	180
11-15	18	18	50	230
16-20	5	5	55	260
> 20	46	45	100	570

Note: Exchange rate: 1 US dollar = RM3.8

Table IV. Distribution of project total construction cost

Table V.
Distribution of type of residential projects

		Structural building system						
					IBS			
Type of residential project (1)	Conventional (2)	Cast *in-situ* table form (3)	Cast *in-situ* tunnel form (4)	Full precast concrete (5)	Composite (6)	Block (7)	Timber (8)	Total (9)
Apartment	21	13	8	11	1	Nil	Nil	54
Condominium	5	3	1	1	Nil	Nil	Nil	10
Terrace house	19	Nil	Nil	2	2	1	1	25
Bungalow	4	Nil	Nil	1	Nil	Nil	Nil	5
Semi-detached	6	Nil	Nil	Nil	Nil	Nil	Nil	6
Total	55	16	9	15	3	1	1	100

take advantage of economies of scale. For full precast concrete systems, apartment was the major share with 11 projects followed by terrace house (two projects), condominium and semi-detached with one project respectively.

Performance comparison between structural building systems using actual residential projects

This section evaluates the performance comparison between structural building systems using actual residential projects quoted by the respondents. Specifically, it focuses on the following:

- actual labour productivity comparison between structural building systems;
- structural cost comparison between structural building systems;
- crew size comparison between structural building systems;
- cycle time comparison between structural building systems;
- impact of quantity (number houses per project) on actual labour productivity;
- impact of workers' daily salary on actual labour productivity; and
- relationship between structural cost and actual labour productivity.

Actual labour productivity comparison between structural building systems

This section studies the actual labour productivity comparison between conventional building system and IBS. IBS is further subdivided into cast *in-situ* table form, cast *in-situ* tunnel form, full precast concrete system (precast concrete wall with precast half slab), composite system (precast concrete wall with cast *in-situ* slab), block system and timber framing system. Respondents were asked to provide the crew size (carpenters, concretors, barbenders, precast panel installers, system formwork installers and crane operators) and working time measured in days required to accomplish the structural element of one unit house. The actual labour productivity is obtained as follows:

$$\text{Actual Labour Productivity} = \frac{\text{Crew size} \times \text{working time (hours)}}{\text{Building floor area } (\text{m}^2)}.$$

Table VI presents the descriptive statistics for labour productivity comparison between structural building systems. The analysis of variance (ANOVA) results indicated that all the building systems were significantly different. Further, Scheffe's multiple comparison was carried out to determine which structural building systems were significantly different and found that the conventional building system was significantly different (F-statistic = 18.605, P-value = 0.000) from IBS. However, the actual labour productivity difference between structural building systems within IBS was found to be insignificant. The mean actual labour productivity for conventional building system was 7.00 manhours/m^2 compared to IBS with 2.10 manhours/m^2. In other words, the conventional building system was 70 per cent less productive than IBS for the completion of the structural element of one unit house. This result was in agreement with previous studies carried out by Peer and Warszawski (1972) indicated that IBS caused labour saving up to 70 per cent in Israel, 50 per cent in Singapore (Poh and Chen, 1998) and Japan (Wakisaka *et al.*, 2000) respectively.

Table VI.
Actual labour productivity comparison between structural building systems

Structural building system (1)	Number of projects (2)	Mean actual labour productivity (manhours/m^2) (3)	Minimum actual labour productivity (manhours/m^2) (4)	Maximum actual labour productivity (manhours/m^2) (5)
Cast *in-situ* table form	16	2.50	0.93	4.30
Cast *in-situ* tunnel form	9	2.14	0.56	4.53
Precast concrete wall with precast half slab system (full precast system)	15	1.80	0.9	2.89
Precast concrete wall with cast *in-situ* slab system (composite)	3	2.00	1.30	3.14
Block system	1	1.38	1.38	1.38
Timber framing system	1	1.0	1.0	1.0
IBS[a]	45	2.10	1.00	4.53
Conventional	55	7.00	2.04	14.95

Note: [a] IBS includes all structural building systems except for conventional building system

Structural cost comparison between structural building system

This section examines the structural cost comparison between structural building systems. Structural costs include material, labour and transportation costs for the completion of the structural element of one unit house. Table VII displays the descriptive statistics for structural cost comparison between structural building systems. Structural cost was found to be insignificantly different among all the structural building systems (F-statistic = 0.581, P-value = 0.677). This result supports the current thinking that the contractors prefer to choose the conventional building system rather than proposing IBS systems since shifting of building system

Table VII.
Structural cost comparison between structural building systems

Structural building system (1)	Number of projects (2)	Mean structural cost (RM/m^2) (3)	Minimum structural cost (RM/m^2) (4)	Maximum structural cost (RM/m^2) (5)
Cast *in-situ* table form	16	278	73	1402
Cast *in-situ* tunnel form	9	210	102	300
Precast concrete wall and precast half slab system (full precast system)	15	242	80	547
Precast concrete wall and cast *in-situ* slab (composite system)	3	170	133	201
Block system	1	247	247	247
Timber framing system	1	178	178	178
IBS	45	243	80	1,402
Conventional	55	330	35	1,804

Note: Exchange rate: 1 US dollar = RM3.8

from conventional to IBS is not motivated by cost factors. Furthermore, most contractors have used the conventional building system for decades.

Crew size comparison between structural building system

Labour represents a significant portion of construction cost in residential projects. The labour cost has dramatically increased to 30 per cent of the construction cost due to rising of standards of living and the levy imposed by the government on foreign workers. Hence, it is important to identify the building system that requires the least labour input.

The respondents were asked to provide the crew size available at the construction site at any time. The crew were those directly involved in the physical work and they include carpenters, concretors, barbenders, precast panel installers, system formwork installers and crane operators. Table VIII shows the descriptive statistics for the crew size for four building systems. The mean crew size required to complete the structural element of one house were 22 workers for conventional building system followed by 17 workers for cast *in-situ* table form system, 18 workers for cast *in-situ* tunnel form system, 18 workers for full precast concrete system, 18 workers for composite system (precast concrete wall and cast in-situ slab), four workers for block system and nine workers for timber framing system. The ANOVA test indicated that there was no significant difference between all the building systems (F-statistic = 1.142, P-value = 0.342). Further, t-test was carried out to determine the difference between conventional building system and IBS in total (average of all building systems in IBS). Results indicated that the conventional building system with crew size of 22 workers and IBS of 18 workers was significantly different (t-value = 2.17, P-value = 0.032) or difference of 18 per cent. This finding is in line with the observation that the conventional building system requires more construction trades than the IBS.

Cycle time comparison between structural building systems

Shorter construction time implies lower site staff overhead and cost saving on equipment rental. This can be achieved through effective and efficient site management. This section compares the cycle time measured in working days between the structural building systems. The respondents were asked to indicate the cycle time required to complete the structural element of one unit house. Table IX

Structural building system (1)	Number of projects (2)	Mean crew size (3)	Minimum crew size (4)	Maximum crew size (5)
Cast *in-situ* table form	16	17	4	41
Cast *in-situ* tunnel form	9	18	9	26
Precast concrete wall and precast half slab system (full precast system)	15	20	7	59
Precast concrete wall and cast *in-situ* slab (composite system)	3	22	17	26
Block system	1	4	4	4
Timber framing system	1	9	9	9
IBS	45	18	4	41
Conventional	55	22	6	76

Table VIII. Crew size comparison between structural building systems

Table IX.
Cycle time comparison between structural building systems

Structural building system (1)	Number of projects (2)	Mean cycle time (days) (3)	Minimum cycle time (days) (4)	Maximum cycle time (days) (5)
Cast *in-situ* table form	16	4.66	2	8
Cast *in-situ* tunnel form	9	4.05	1	7
Precast concrete wall and precast half slab system (full precast system)	15	3.81	1.45	12
Precast concrete wall and cast *in-situ* slab (composite system)	3	3.1	2	5
Block system	1	4	4	4
Timber framing system	1	0.75	0.75	0.75
IBS	45	4.00	0.75	12
Conventional	55	17.00	3	49

shows the descriptive statistics for the cycle time for all the structural building system. The mean cycle time for conventional building system was 17 days, 4.66 days for cast *in-situ* table form system, 4.05 days for cast *in-situ* tunnel form system, 3.81 days for full precast concrete system, 3.10 days for composite system (precast concrete wall and cast *in-situ* slab), four days for block system and 0.75 days for timber framing. The ANOVA test indicated that there was significant difference between all the structural building systems. Further, Scheffe's multiple comparison indicated that the conventional building was significantly different from the other six structural building systems (*F*-statistic = 25.421, P-value = 0.000). Nevertheless, no significant difference was found within structural building systems categorised under the IBS. On average, the cycle time required to complete one house using conventional building system was 17 days while the IBS required four days. In term of percentage, IBS required 76 per cent less cycle time than conventional building system.

Impact of workers' daily salary on actual labour productivity

This section presents the relationship between workers' daily salary and actual labour productivity. The respondents were asked to indicate the daily salary for unskilled, semi-skilled and skilled workers. The mean workers' daily salary were the average value of the three type of workers. The mean daily salary for unskilled, semi-skilled, skilled workers and workers' leader were RM35, RM45, RM60 and RM100.

The Pearson's correlation test between workers' daily salary and actual labour productivity indicated that insignificant correlation between the two variables with correlation coefficient (r) of 0.024 with significance level more than 0.05. This implied that the workers' daily salary has weak prediction for actual labour productivity.

Impact of quantity completed on actual labour productivity

The respondents were asked to indicate the quantity completed measured in term of number of houses per project. Pearson's correlation test indicated that quantity completed has strong negative correlation with actual labour productivity (correlation coefficient of -0.275 with significance level less than 0.01). This suggested that as the number of unit house increased, actual labour productivity improved. In other words, the manhours required to accomplish one unit of house reduced. Better actual labour productivity was attributed to workers' learning effect and economies of scale. As the workers carried out repetitive work, their skill and experience improved.

Relationship between structural cost and actual labour productivity

Poh and Chen (1998) studied the relationship between building system cost and buildable design appraisal system (BDAS). A structural system with higher buildable score resulted in more efficient labour usage in construction project and therefore higher site productivity. The result found that there was no significant relationship between construction cost and buildable score. The major discrepancy in the study was that construction cost not only consists of structural cost, but also mechanical and electrical costs. This might impart the invalidity of the relationship between construction cost and BDAS.

This section studies the relationship between structural cost (excluding architectural, mechanical and electrical costs) and actual labour productivity for all the structural building systems. Pearson's correlation test was carried out to determine the interaction between structural cost and actual labour productivity. Result indicated insignificant interaction between them (correlation coefficient of 0.024 with significance level more than 0.05). The result is in agreement with the study carried out by Poh and Chen (1998). The main reason for the lack of distinct relationship between them was that the structural cost includes labour, material and transportation while the actual labour productivity was related only to the efficient usage of labour. Hence, future studies should attempt to study the relationship between structural cost and total productivity (labour productivity, material productivity and transportation productivity).

Conclusion

This paper has evaluated the construction performance comparison between the conventional building system and IBS in terms of actual labour productivity, structural cost, crew size, and cycle time. Actual labour productivity for conventional building system of 7.0 manhours/m^2 was found to be significantly different from IBS of 2.1 manhours/m^2 or difference of 70 per cent. This result was in agreement with studies carried out by Peer and Warszawski (1972) indicated that IBS caused labour saving up to 70 per cent in Israel, 50 per cent in Singapore (Poh and Chen, 1998) and Japan (Wakisaka *et al.*, 2000) respectively. However, the structural cost between conventional and IBS was found to be insignificantly different in Malaysia. This result supports the current thinking that the contractors prefer to choose conventional building system rather than proposing IBS system since shifting of building system from conventional to IBS is not motivated by cost factors. Furthermore, most contractors have been exposed and trained in conventional building system for decades and there is an abundance of cheap foreign workers in Malaysia. Shifting to IBS seems to be an uphill task, unless the government imposes a legislative requirement on the use of IBS or redefines the market so as to earmark a set quota of IBS projects.

The crew size comparison between structural building systems indicates that the conventional building system of 22 workers was significantly different from IBS of 18 workers or difference of 18 per cent. On the other hand, the cycle time per house for conventional building system of 17 days was found to be significantly different from IBS of four days or difference of 76 per cent. From these results, it could be concluded that the difference in actual labour productivity between conventional and IBS was mainly contributed by the cycle time (difference of 76 per cent) rather than the crew size (difference of 18 per cent). Shorter cycle time implies that total project construction time would also be reduced, hence minimising management overhead and meaning that owners can occupy their house early.

The analysis of relationship between workers' daily salary and actual labour productivity indicates a weak linear relationship between them. In other words, the workers' daily salary is a poor independent variable for predicting actual labour productivity. Similarly, the structural cost was also found to have insignificant relationship with actual labour productivity. Nevertheless, the quantity completed measured in terms of number of house per project was found to have strong negative linear relationship with actual labour productivity. This suggested that as the number of unit house increased, the actual labour productivity improved due to learning effect and economies of scale.

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Corresponding author
W.P. Lee can be contacted at: leewp@mail.utar.edu.my