Combined Statistical Analysis and Management Measure Optimization of Prefabricated Construction Projects

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Abstract. China’s prefabricated buildings appear increasingly mature in their techniques thanks to the needs of developing green buildings and the impetus of national policies enacted in various levels. Despite that, deficiencies are still common in comprehensive results and management, impeding the further development of China’s prefabricated buildings to a certain extent. This paper conducts an analysis of the project results and a comparative analysis of the combined statistics pertaining to the identically designed prefabricated structures and cast-in-place concrete ones utilized in a residential project based on the method of combined statistical analysis. It is demonstrated that prefabricated buildings prove superior in quality and schedule, and meanwhile have some disadvantages that are also revealed in this paper. The analysis serves as a basis for effective measures of optimizing the management of prefabricated construction projects to be proposed so as to further boost the results of prefabricated buildings.

1. Project Profile
This project contains five residential buildings, covering a total area of 118,356 m². It is contracted out to a design unit and a construction unit respectively by the construction employer in a traditional project management mode, scheduled to be completed within 15 months.

In this project prefabricated reiteration plates are utilized from the 14th to 28th storeys in Block B, and prefabricated staircases from the ninth above. They are hoisted and directly assembled, leaving redecoration unnecessary. The prefabricated reiteration plates and prefabricated staircases, with a maximum weight of 2.1 t and 3.6 t respectively, are vertically transported from the hoisting area to unloading area by a JL150 tower crane that operates within a radius of 40 m. Block A is identical to Block B in its layout, but differs in its structures since nothing more than cast-in-place ferroconcrete ones are adopted in the whole building. Project results yielded by the prefabricated buildings in Block B are analyzed as follows.

2. Analysis of Project Results
2.1. Higher quality
The simpler assembly process, and less cast-in-place and manual work of the prefabricated reiteration plates effectively minimize the incidence of quality problems arising from the difference in works’ proficiency. The requirements on concrete strength in prefabricated structures are satisfied through steam curing, which further guarantees construction quality.

Such structures have high appearance quality and manufacturing accuracy. Consequently, less repair is required for components, delivering a working face favorable for decorative work, which
decreases the waste of finishing materials. Additionally, the prefabricated staircases are overall made
of fair-faced concrete whose formation is so even and dense, and color so uniform that no extra work
is needed for decorative layers. Thanks to that, the results are yielded presenting elegant formation,
construction convenience and guaranteed quality.

2.2. Fewer environment impacts
Prefabricated construction shrinks the demand for cast-in-site concrete, producing less waste. 
Meanwhile effluent is reduced since less water is used to clean concrete mixing carriers, pump
machines and pump pipes. Moreover, less field operation owing to prefabricated hoisting work
prevents the otherwise louder construction noise.

2.3. Shorter construction period
A comparison of construction period demonstrates that the prefabricated staircases in Block A takes
87% less time than the traditional cast-in-place staircases in Block B. Time spent on the prefabricated
reiteration plates in each storey is 0.5 h less than that spent on traditional cast-in-place plates, a
difference not so noticeable.

2.4. Less resource consumption
Statistical data on materials and energy consumption gathered by comparing the traditional mode of
construction and prefabricated one indicate that the latter utilizes 68% less roof modules and 49% less
roof keels. Meanwhile, the prefabricated structures lead to a drastic decline in water used for curing
and rinsing concrete, and imposes an effective control on steel scraps. Nevertheless, the reduction in
electricity consumed during construction appears slight due to a higher frequency of use of machinery
required for component hoisting.

3. Combined Statistical Analysis

3.1. Cost analysis

3.1.1. Prefabricated reiteration plates
A comparison of labor, materials and machinery between the cast-in-place plates used in Block A and
the prefabricated reiteration ones in Block B is as shown specifically in Table 1:

| Number | Project | Cast-in-place (A#) | Reiteration plates (B#) | Compare results (A#-B#) /yuan |
|--------|---------|--------------------|-------------------------|-------------------------------|
|        |         | Quantities | Total price | Quantities | Total price |                                      |
| 1      | Labour cost | 18376.07 | 28961.48 | -10585.41 |
| 2      | Steel bar | 8.13 | 39674.40 | 6.32 | 30875.76 | 8798.64 |
| 3      | Timber | 50*100mm | 1190 | 32130 | 680 | 18360 | 13770 |
| 4      | | 100*100 mm | 260 | 14560 | 256 | 14336 | 0 |
| 5      | moulds | 2440*1220mm | 230 | 33350 | 138 | 19933.33 | 13416.67 |
| 6      | Cast in place concrete | 63.2 | 27808 | 35.81 | 15756.40 | 12051.60 |
| 7      | Prefabricated units | 0 | 0 | 28.71 | 38694.23 | -38694.23 |
| 8      | other | 1 | 1112.13 | 1 | 1626.07 | -513.94 |
| 9      | Machinery | 1 | 471.51 | 1 | 5165.38 | -4693.87 |
| 10     | other | 1 | 348.26 | 1 | 201.58 | 146.68 |
The cost comparison between the prefabricated reiteration plates and cast-in-place ferroconcrete ones demonstrates that the former totally cost 6,303.87 yuan more in each storey. The reasons underlying the increase are as follows:

For one thing, each vehicle carries 12 prefabricated reiteration plates on average, resulting in a high amortization cost in transportation. For another, among the total cost of around 1.02 million yuan spent in constructing prefabricated reiteration plates, about 240,000 yuan is spent on eight sets of moulds, accounting for 24%. It follows that the higher cost in prefabricated structures is principally attributed to the expenses disbursed for component transportation and moulds.

### 3.1.2. Prefabricated stairs

A comparison between the same storey in Block A and B has the difference in economy between traditional and cast-in-place staircases shown in Table 2:

| Project                        | Materials (yuan) | Labour (yuan) | Machinery (yuan) | Total price (yuan) | Time (minutes) |
|--------------------------------|------------------|---------------|------------------|-------------------|----------------|
| Fabricated Stairs              | 3950             | 100           | 100              | 4150              | 20             |
| cast-in-place stairs (structure) | 2750             | 400           | 40               | 3190              | 150            |
| cast-in-place stairs (Decoration) | 900              | 700           | 250              | 1850              |                |

The prefabricated staircases cost 1850+3190-4150=890 yuan less than the cast-in-place ferroconcrete ones during construction.

### 3.1.3. Labor cost

The same storey in Block A and B is compared pertaining to their man-hours as shown in Table 3:

| Building number | form fixer | Steel Fixer | Prefabricated workers | installer | Total |
|-----------------|------------|-------------|-----------------------|-----------|-------|
| A#              | 10         | 10          | 0                     | 7         | 27    |
| B#              | 9          | 9           | 12                    | 10        | 40    |

The prefabricated reiteration plates need extra prefabricated and hydropower workers that add up to 15, increasing labor cost in each storey by 10,585.41 yuan in comparison with the cast-in-place ferroconcrete plates.

### 3.2. Construction schedule analysis

Block A and B have the same storey compared pertaining to working time as shown in Table 4:

| Building number | Formwork (h) | Binding of bottom reinforcement or hoisting (h) | Water and electricity installation (h) | Binding of bearing negative reinforcement (h) | Concrete pouring (h) | Total (h) |
|-----------------|--------------|-----------------------------------------------|---------------------------------------|-----------------------------------------------|----------------------|-----------|
The comparative data analysis reveals that the prefabricated reiteration plates consume less time on formwork and concrete pouring, but more in assembly and water and electricity installation. Taken together, time spent on the prefabricated reiteration plates is 0.5h less than that spent on the cast-in-place ferroconcrete plates.

4. Management Optimization
The above statistical analysis indicates that such prefabricated project yields better results in quality and schedule that still have room for improvement, while facing the problem of construction cost being a little too high. Consequently, management should be further optimized to improve the overall benefits gained by controlling project cost, quality and schedule.

4.1. Whole-process cost control starting from schematic design

4.1.1. Design stage
To realize the purpose of cost control requires to start from the stage of schematic design. Either a higher assembly proportion or lower cost plays an indispensable role. For that reason, the incremental costs of such components as beams, slabs, pillars and shear walls incurred due to the change in assembly proportion should be determined so as to identify the optimum assembly proportion. Afterwards whether to cast a certain component in place or pre-cast should be decided based on cost analysis of those components showing great incremental costs by applying value engineering before initiating subsequent design work. In doing so, costs can be controlled as early as the schematic design stage. At the stage of construction documentation design, partitioning and deepening are two new steps in prefabricated buildings. The first step allows each profession to be fully considered when partitioning components, while the latter requires component manufacturers and constructors to collaborate with each other and meanwhile take all professions into consideration in designing from a holistic perspective. To meet the desired goal of cost control, component manufacturing and installation cannot be neglected even as early as the design stage. Additionally, the concept of standardized design and cost control should be thoroughly integrated into design stage, while connected nodes should be standardized which can reduce beam sections in this project from 21 types to 15, a decline of 28.5%. As a result, less complexity involved can facilitate component manufacturing and shorten manufacturing period, meanwhile reducing cost to some extent.

4.1.2. Component manufacturing
Factories must strictly execute the predetermined scheme and comply with the drawings and specifications when manufacturing components. A simple and efficient manufacturing plan should be drawn up in accordance with data on the total quantity and specifications of each component. Meanwhile, critical procedure during component manufacturing should be seriously controlled, while quality in the whole manufacturing process should be kept under supervision. Better quality assurance result in less unqualified components, contributing to cost reduction.

4.1.3. Field construction
At this stage, great uncertainties cause difficulties commonly facing construction period control, imposing a ripple effect on cost control. In the meantime, deficiencies and contradictions generated during design and manufacturing will unavoidably emerge at this stage, compounding the difficulty in controlling cost. It follows that more efforts put into cost control at the construction stage play a key part in yielding more economic returns in this project. Cost during construction arises from vertical transportation, pre-embedded pipe fittings, and labor, machinery and tools required for installing components. The construction unit is suggested to keep improving its manner of execution and
techniques based on practical situation, and refining construction procedure when various professions operate simultaneously, so that construction cost can be reduced and speed improved.

4.2. Whole-process quality control taken by the general contractor
In regard to quality control the general contractor must coordinate each party engaging in design, manufacturing, construction and other activities. To meet the quality requirements on prefabricated buildings entails all-dimensional quality control. Firstly, design as the primary stage is of great importance to the overall quality of prefabricated buildings. At this stage project designers are supposed to thoroughly communicate with component manufacturers and staff managing field installation, and coordinate each party involved to participate in designing the detail drawing of components so as to produce an optimal design. Moreover, the general contractors must ensure that relevant specifications are conformed to regarding the materials used in components whose quality justifies that of the prefabricated buildings. Lastly, relevant quality control systems should be formulated, seriously executed and controlled based on a full consideration of the characteristics at the construction stage of prefabricated buildings.

4.3. Schedule control by fully utilizing BIM technology
Schedule control in prefabricated buildings should still involve design, manufacturing, construction and maintenance. The BIM information center allows various participants and professions to communicate with each other and share data processed to form a dynamic timetable in order to render schedule control more comprehensive. It also serves as a platform for each party to coordinate, ensuring that the project is implemented efficiently and orderly. The schedule control system based on BIM is as shown in Figure 1:

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   Schedule
     |      Optimization
     |       Monitoring
     |         Comparison
     |           Adjustment

   4D simulation
   Dynamic site management
   Dynamic resource management

   Real-time tracking
   Construction simulation

   Collision check
   Design
   Virtual Reality

BIM information platform
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Figure 1. Schedule management system

The schedule control at design stage, which overlaps with the early stage of manufacturing and construction, mainly concerns control on plot. Designers draw up a plan prior to the initiation of design, and carry out real-time tracking during this stage to check whether the schedule proceeds as planned. BIM works to enhance the efficiency of schedule control. The contradictions detected as early as possible by adopting the analytical model of collision check buy time for their earliest adjustment. The resulting avoidance of manufacturing and installation problems arising from collision can prevent work period being delayed. During manufacturing components, the key to schedule
control is of relevance to the time allocated to the production of each component and the supervision of manufacturing process. The BIM platform used in this project enable manufactures to easily and quickly obtain materials required for the prefabricated project and confirm the type and quantity of prefabricated structures. It endows manufacturing control with a higher precision. Staff of the general contractor can monitor and control the situation of component manufacturing in time from the BIM center before informing component manufacturers of existing problems quickly identified by referring to the target plan. Designers are required to provide on-site guidance in factories during manufacturing, while manufacturers should also be fully involved in construction site. Accordingly, the coordination between each stage can accelerate the overall schedule. During construction the project manager organizes professionals to prepare the schedule of construction and upload it to the BIM platform. Construction schedule can be simulated through the BIM technology to quickly discover the time of delay, for which specific solutions should be proposed in order to ensure that construction is carried out as planned.

In conclusion, the prefabricated buildings yield satisfying results in construction efficiency, energy conservation and emission reduction, environmental impacts and quality improvement, but meanwhile face the problem of construction cost being a little too high. Nevertheless, further refinement of management measures can from a holistic perspective of the prefabricated buildings resolve the problem of cost on the high side while maintaining a steady optimization of quality and schedule control, so that the overall benefits of project management can be maximized.

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