SCHEDULING FOR HIGH-RISE BUILDING CONSTRUCTION USING SIMULATION TECHNIQUES

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SUMMARY

High-rise buildings are commonly built in densely populated countries or urban areas. A balanced floor construction cycle is critical for construction of the frame structures. The objectives in scheduling the floor cycle are to ensure smooth flows of resources and to optimise the use of formwork and other materials. The floor area is usually divided into zones to allow the labour force and formwork materials moving between zones. The preparation of the floor construction cycle would therefore be a resources allocation exercise. However, the process is complex and difficult when it is done manually. Floats are created deliberately in the schedule to ensure the balance in resources and to provide buffers. Simulation that can demonstrate the real world operations is an effective tool in handling this scheduling problem. This paper examines the constraints in planning the floor cycle and the effects of working period on the overall schedule. Network based simulation model is used to investigate the problems. It is noted that variations in working periods have significant impacts on the time schedule. A saving of 37.2% in time could be achieved when the working period is extended by 20%. The findings indicate that simulation can be used to assist planners to improve their decisions and decide the strategies in scheduling and reviewing the floor construction schedule.

Keywords: Scheduling, simulation, floor construction cycle.

INTRODUCTION

High-rise buildings are still the essential form of building structure constructed extensively in urban areas, in particular, in the hearth of the commercial zones of metropolitan cities. On the other hand scarcity of land supply encourages the construction of high-rise buildings. With a population of 6100 people per square kilometre, Hong Kong has built lots of high-rise residential, industrial and commercial buildings over the last 40 years. Residential buildings of over 40-storey are very common in Hong Kong and a 70-storey high residential block was completed in 2002 whereas a 80-storey building is under construction. In scheduling the floor construction cycle, a simple approach is to adopt a constant duration for the construction of the typical floors. However, this always induces a false impression to site personnel that the construction processes are simple and could be achieved easily. For the construction of high-rise buildings, site planning including activity scheduling and site production layout has to be reviewed and re-plan from time to time in practice as site conditions and resources are dynamic and uncertain. Although Genetic Algorithms and other AI techniques have been used by researchers in optimising complex problems, practitioners are sceptical in applying these techniques with which they are not familiar. This paper evaluates the scheduling of typical floor construction using network based simulation techniques, a more practical and easily apprehensible approach, to improve decision making in site planning in response to the changing site conditions.

TYPICAL FLOOR CONSTRUCTION CYCLE

In the construction of a high-rise building, one of the planning objectives is to ensure the early completion of the structural frames to generate floor areas for the execution of finishing works, building services installation and internal fitting out. The completion of the structural frames is therefore critical in the overall programme. For a building of 42-storeys high, it may consist of 40

typical floors resting on two podium floors. It is not surprised to have construction programme aiming at a 2-day or 4-day cycle for the typical floors. It would be a time-cost trade off problem in determining the duration for a project in project-wise considerations or in selecting construction methods for major construction activities. Planning engineers have to balance the resources inputs and the duration for activities in order to ensure a smooth flow of work sequences in meeting the project duration.

In minimizing the construction costs for constructing a reinforced concrete frame, the formwork cost is one of the key concerns. It is well recognized that formwork is a temporary work for forming moulds for wet concrete. The cost of formwork is highly related to the number of re-use or re-cycling. It is a general assumption that a set of formwork can be re-used for at least six to eight times and 100 times for timber and steel form respectively. Steel formwork systems are prevailing in high-rise building construction because of their durability, good concrete finish and environmental sustainability. However they are expensive unless the formwork system is designed to yield a high number of re-use. Taking the above example, a set of formwork for 40 typical floors is still uneconomical. Consequently, it has to subdivide the floor area into zones in order to generate a high number of re-use. The subdivision of a floor into two or four zones will be a feasible solution. It is obvious that dividing the floor into four zones would yield a high number of re-use, that is 160 times. The following example shows the arrangements of a 6-day floor cycle for a typical residential building block.

Construction of a 42-storey building

Each floor is divided into four zones. One set of steel wall form covering the quantity of one zone and two sets of slab timber forms with each set covering the whole area of one floor are used. In order to speed up the construction, precast façades and semi-precast slabs are employed. The construction cycle aims at ensuring smooth and balanced resource allocations between trade workers, concreting work and formwork installation. As a result the resources rotate horizontally between zones at the same floor level and move upward to the upper floor in the next cycle. Figure 1 shows the schedule for a typical 6-day floor construction cycle including ten critical activities. The schedule is prepared assuming that the activities are carried out at constant duration. However, the duration of activities varies due to factors such as supply of materials, skill of workers, weather and efficiency of plant and equipment.

On the other hand, material hoisting plays an important role in high-rise building construction. As the building 'grows', the transportation time increases and thus extends the duration for the crane-related activities. Researchers have studied and developed the optimisation models for cranes aiming at reducing the transportation costs (Rodriguez-Ramos and Francis, 1983; Choi and Harris,1991 and Zhang, Harris and Olomolaiye,1996). Leung and Tam (1999) developed prediction models for improving the prediction of hoisting times.

One of the objectives of this study is to use the simulation technique to review the typical construction floor cycle. This research attempts to see if there are any potential improvement on scheduling using construction simulation.

SIMULATION MODEL FOR TYPICAL FLOOR CYCLE

Simulation techniques have been used to predict activity duration and improve planning (Halpin and Riggs 1992, Shi 1999 and Zhang, Shi and Tam 2002). However, the building up of simulation models requires planners to have a good knowledge of simulation. A network based simulation has been used in this study. This simplifies the skills and knowledge required for modelling a simulation network as general simulation programme can be difficult for general users (Shi and AbouRiz 1997). Planners who have the knowledge in constructing critical path network and bar charts could be able to use the simulation model. The constructing of simulation network for modelling is similar to the critical path network using the 'activity on node' format except that loops are allowed to show the re-cycling of resources. During the simulation process, the activities may either in an active if the constraints are met or otherwise in an idle mode. The typical construction floor cycle shown in Figure 1 can be easily developed into a simulation network as shown in Figure 2.

Although only one floor cycle is shown in the network, it covers the activities in the four zones, which are handled within the simulation algorithm. The ten activities are scheduled in a sequential order. Two loops are teed off from the main network indicating the dependence relationship between installation of precast façade, the activities for wall construction and crane-related activities. Normally, a tower crane can only be installed for a building block owing to both economic reasons and space availability. Therefore, the crane can only serve one activity at one time and it is important to optimise the usage of a tower crane which is one of the critical resources in high-rise construction (Leung and Tam 2001). A 'Start' and 'Stop' node is assigned in the network for controlling the numbers of simulation. During the simulation process, activity boxes are attached with a coloured spinning icons showing their status. Resources shared by activities can be represented by graphics moving between the activities boxes.

SIMULATION FOR TYPICAL FLOOR CONSTRUCTION CYCLE

In order to optimize the duration of a floor cycle or to determine the daily schedule, modellers can modify the duration of the activities to suit the site conditions. It has to point out that the duration of the activities can be shortened or extended by increasing or decreasing the input resources, mainly the human resources in concrete frame construction generally. Table 1 shows the duration for the activities of a typical floor construction cycle.

Activity	Duration (hours)		
	Mean	Maximum	Minimum
Precast facade fixing	1.00	1.25	0.85
Wall steel fixing	7.00	6.75	7.15
Wall form fixing	2.25	2.50	2.00
Wall concreting	4.00	4.50	3.75
Stripping form	2.25	2.50	2.00
Semi-precast slab fixing	3.00	3.50	2.75
Slab form fixing	7.50	8.00	7.00
Beam and slab steel fixing	8.00	9.00	7.50
Electrical conduiting etc.	2.50	3.00	2.00
Beam and slab concreting	4.00	4.50	3.75

Table 1 Activity duration for a typical floor construction cycle

In order to generate realistic results, the duration assigned for the simulation has taken into account the effects on hoisting times due to variations in hoisting height. For example, the hoisting and fixing of eight precast façades takes about 51 minutes at the lower floors and 75 minutes at the upper. Planners can adjust the duration if they identify significant differences between the original input and the actual site conditions. Alternatively, planners can carry out simple work study techniques on site to collect data for predicting the hoisting time.

Apart from modifying the duration to suit the dynamic site conditions, planning engineers can review the effects of working hours for a working day to a floor cycle. Examining the standard floor cycle shown in Figure 1, it is evident that there are idling times in the schedule. The idling times are created for levelling the resources. However, manual resource levelling is complex and difficult and optimum solution cannot be easily found. The numbers of working hours for a working day can be input as a constraint in the simulation. In Hong Kong, most of the residential areas are densely populated and the government has imposed stringent noise control ordinance to restrict the working hours for using noisy construction plant and equipment. The normal working period to which there is no restriction is between 7:00am and 7:00pm. On the other hand, the normal working hours for the building industry lie between 8:00am and 6:00pm. Any time beyond the normal working hours, the trade workers need to be paid with an overtime allowance of 50% of their basic wages. It is vital to minimize the labour costs while meeting the programme of the project. In this study, four working

period scenarios have been reviewed by using the simulation model.   The summary of the simulation results is shown in Table 2.

Simulation Results

Working period	Activity Duration	Cycle (days)	Compared with 6-day cycle
8:00 - 18:00	Constant	6.21	3.5
8:00 - 18:00	Variables	4.45	-25.8
8:00 - 19:00	Variables	4.41	-26.5
7:00 - 19:00	Variables	3.77	-37.2

Table 2 Simulation results for different 'Working Period'

In the four scenarios, the first working period follows the industry normal working hour and constant activity duration was used.   The remaining scenarios have been tested with stochastic activity duration. The simulation results confirm that the first scenario is working approximately on a 6-day cycle. However, it is noted that there are significant saving in time when the durations of activities are varied. In the second scenario, there is a saving of 25.8% even the activities are scheduled within the normal working period.   However, when the working period is extended by one hour in the third scenario, further decrease in time is minimal.   In the last scenario, the working period is extended by two hours; a further saving of 11.4% (a total saving of 37.2%) is yielded.   It means that the increase of the working hours by 20% is not effective since the labour costs will be increased by 40%. This is a typical time-cost trade off problem when time is approaching to the crash time solution.

SELECTION OF APPROPRIATE WORKING SCHEDULE

The simulations described above provide alternatives for planners to make decisions on initial scheduling and subsequent updating.   The simulation results enable planners to locate the upper limit of the floor cycle, ie approaching to the crash time solution. However, it is a general rule in planning that the normal time should be used in the planning stage unless the project duration would have already been overrun.   An aggressive project manager may consider applying the second scenario in order to shorten the frame construction by 62 days (ie. 40 x [6.0 – 4.45]) without spending overtime payments. If the project is undergone delay, a more drastic decision will be to extend the working period by two hours as if in the fourth scenario.   Therefore, when deciding the appropriate floor cycle duration, planners have to review the factors and the merits prior to determine the strategies.

CONCLUSION

This paper examines the application of simulation techniques in evaluating and scheduling the floor construction cycle of a high-rise building. The typical floor construction cycle is always the main concern of planning engineers. The early completion of the floor slabs releases working areas for the subsequent activities. The initial planning and the subsequent re-scheduling are therefore important for the successful management of a high-rise building project. The traditional schedule for a typical floor aims at balancing the resources, in particular the formwork system, to assure a steady movement of resources while maintaining the progress.   Simulations for the floor cycle using stochastic duration and different working period had been conducted in this study. The simulation results generated show that the duration for the floor cycle could be shortened by 25% to 37%.   The shortening is achieved by reducing the idling time of the resources.   In deciding the duration of the floor cycle, planning engineers have to consider the project budget because additional overtime costs for labour would be incurred. The simulation results could provide useful information for planners to decide upon their strategies in scheduling a typical floor construction cycle at different stages of the project.

This paper reviews the potentials of simulation in improving the quality of construction planning. However, the scheduling and simulation are generally compiled separately. Further study can be

extended to investigate the possibilities of integrating the overall processes to produce a user-friendly platform for practitioners.

ACKNOWLEDGEMENTS

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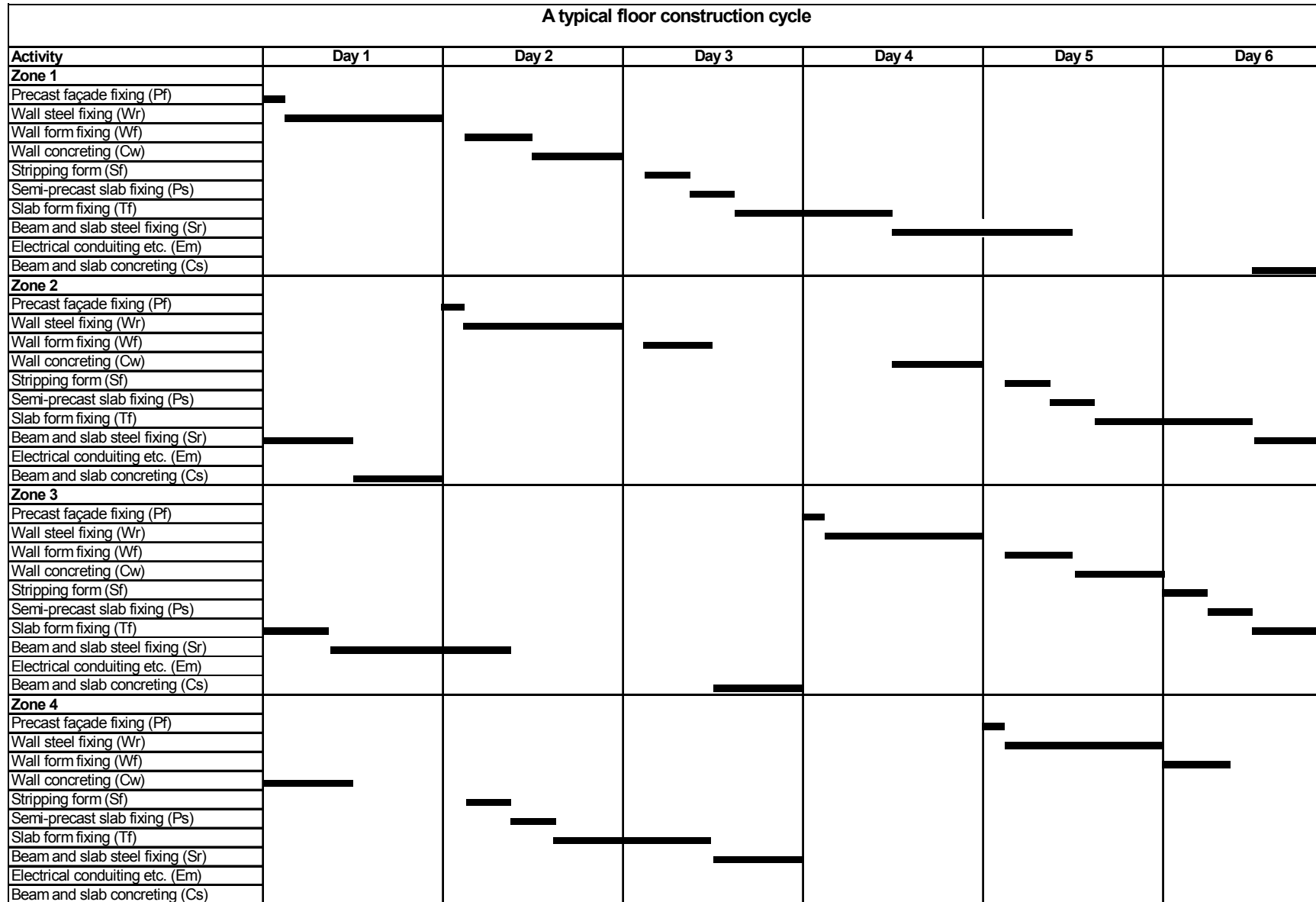
A typical floor construction cycle

Activity	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6
Zone 1						
Precast façade fixing (Pf)						
Wall steel fixing (Wr)						
Wall form fixing (Wf)						
Wall concreting (Cw)						
Stripping form (Sf)						
Semi-precast slab fixing (Ps)						
Slab form fixing (Tf)						
Beam and slab steel fixing (Sr)						
Electrical conduiting etc. (Em)						
Beam and slab concreting (Cs)						
Zone 2						
Precast façade fixing (Pf)						
Wall steel fixing (Wr)						
Wall form fixing (Wf)						
Wall concreting (Cw)						
Stripping form (Sf)						
Semi-precast slab fixing (Ps)						
Slab form fixing (Tf)						
Beam and slab steel fixing (Sr)						
Electrical conduiting etc. (Em)						
Beam and slab concreting (Cs)						
Zone 3						
Precast façade fixing (Pf)						
Wall steel fixing (Wr)						
Wall form fixing (Wf)						
Wall concreting (Cw)						
Stripping form (Sf)						
Semi-precast slab fixing (Ps)						
Slab form fixing (Tf)						
Beam and slab steel fixing (Sr)						
Electrical conduiting etc. (Em)						
Beam and slab concreting (Cs)						
Zone 4						
Precast façade fixing (Pf)						
Wall steel fixing (Wr)						
Wall form fixing (Wf)						
Wall concreting (Cw)						
Stripping form (Sf)						
Semi-precast slab fixing (Ps)						
Slab form fixing (Tf)						
Beam and slab steel fixing (Sr)						
Electrical conduiting etc. (Em)						
Beam and slab concreting (Cs)						

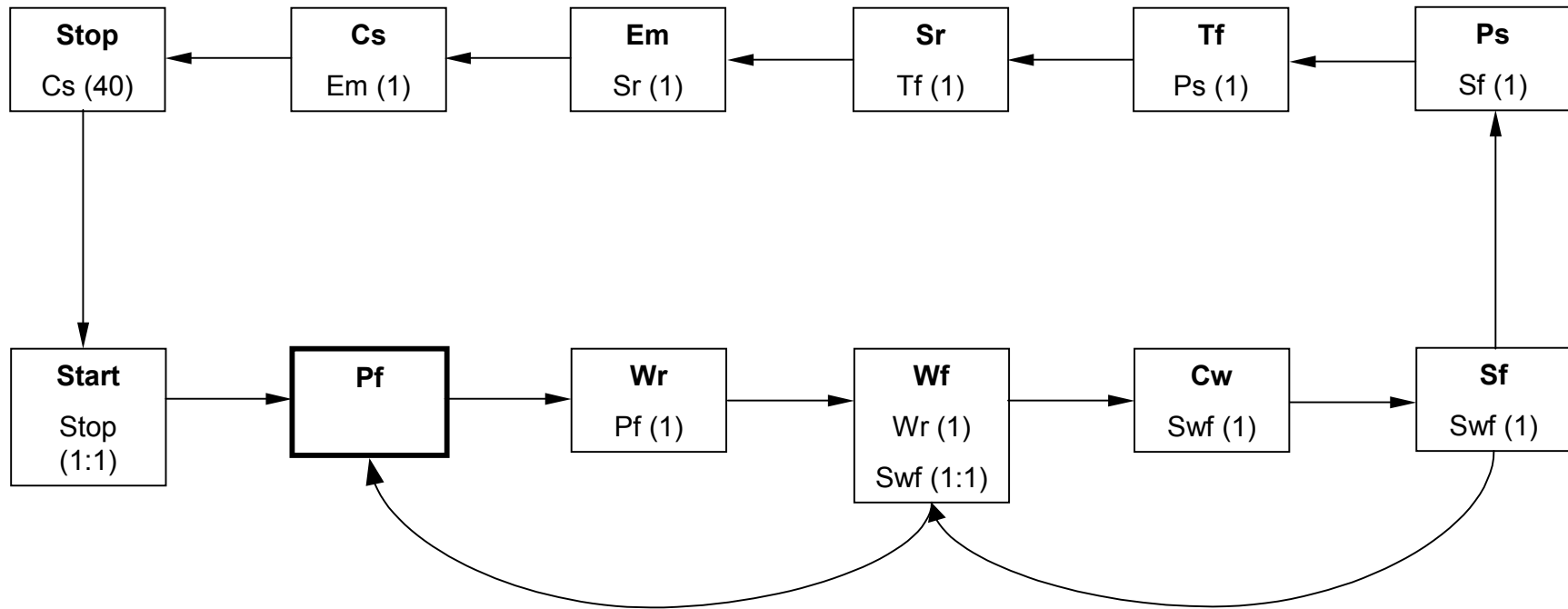**Figure 1** Typical floor construction cycle for a high-rise building

Figure 2 Typical floor construction cycle represented in simulation network