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The application of JIT philosophy to construction: a case study in site layout

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The just-in-time (JIT) philosophy has been used in the manufacturing industry for some forty to fifty years. This system increased not only the productivity of the industry but also the quality of its products. Explorative studies have been completed in recent years to see how JIT can be applied into the construction industry to reap the benefits of the system. Most of these studies have concluded that it is possible to apply the techniques of JIT in the construction industry with some modifications. Taking into consideration that one of the key components of site management is concerned with waste management (i.e. bringing wastage down to the minimum), this study focuses on applying JIT for site layout to improve productivity and quality. By eliminating waste on site, controlling the movement of inventory coming into the site and within the site, and controlling the usage of mechanized plant and equipment, smooth work flow can be achieved.

Keywords: Just-in-time, construction management, site layout, productivity, quality

Introduction

The just-in-time (JIT) system was promoted in the early 1950s by Mr Taiichi Ohno of Toyota Motor Corporation and the creator of the Toyota Production System. The JIT concepts were used in the manufacturing sector in Toyota Motor Corporation and proved to be a success as the cars manufactured were of better quality and reliability, productivity was improved and reduction of costs in maintaining inventory levels and storage space was achieved. Although Toyota was not the first company to use JIT, it is widely recognized as the firm that has done most in promoting and developing the concept, both in Japan and abroad.

Although a number of different factors came together to help achieve reliable deliveries of lower costs and higher quality products from cramped and antiquated factories in Japan in the past, the following three are usually regarded as being the principal ones.

1. Lack of space. Unlike factories in western countries, Japanese firms did not have the luxury of shifting from constricted city locations to less built-up sites to generate more space. The land constraints in Japan also meant that suppliers in Japan are not as widely distributed geographically as they are in say the United States (Lim and Low, 1992).
   Realizing that frequently most of the space in a typical factory is used for storage and not for actual manufacturing, the Japanese cleared the space used to hold inventory by: (i) looking for suppliers who could deliver raw materials to the factory floor; (ii) speeding up of work progress by reducing manufacturing batch sizes and lead times; and (iii) using a system that is able to meet customers' orders more quickly.
2. Adoption of new quality techniques. Getting rid of all the stocks of raw materials and work in progress also removed a lot of the safety margin needed to cater for rejected or faulty goods. Therefore, better quality in the manufactured goods was required.
3. Development of the 'Toyota Production System' (discussed in greater detail below).

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Despite the fact that the JIT philosophy flourished in Japan, western managers paid little attention to it until 1980 when Kawasaki in Lincoln, Nebraska, successfully adopted it. Since then, numerous organizations such as Hewlett-Packard, General Electric, IBM and Harley Davidson have utilized JIT successfully to improve their manufacturing operations (Lim and Low, 1992).

In the construction industry, although much has been written on increasing productivity in terms of labour, time and material wastage and how JIT can improve on this (Lim and Low, 1992; Low and Tan, 1997a,b), there has been little focus on how a construction site layout can be improved to increase productivity. This paper therefore aims to examine the JIT philosophy and how it can be adopted for site layout on construction sites. The main objectives of this paper are: (a) to provide a general understanding of the JIT concepts; (b) to highlight the relevance of the JIT concepts in raising productivity and eliminating waste in the construction industry and (c) to examine how the JIT concepts can be successfully applied for site layout on a construction project. An in depth case study in Singapore on the successful application of JIT concepts in the Regent Heights Condominium will be examined for this purpose.

The JIT philosophy

JIT is a Japanese management philosophy applied in manufacturing which involves having the right items of the right quality and quantity in the right place and at the right time (Cheng and Podolsky, 1993). Its disciplined approach improves overall productivity and eliminates waste (Voss, 1987). It stimulates workers to identify and resolve problems and operational weaknesses which hinder organizational effectiveness and efficiency (Schonberger, 1982; Hall, 1983). JIT is a philosophy which takes total pride in making the business lean, more simple and effective to operate and with a higher degree of integration (Mortimer, 1986).

By contrast, the characteristics of the traditional manufacturing process or 'just-in-case' (JIC) system are: systems, materials and parts are pushed from one process to the next, regardless of whether they are needed or will be worked on by the next process; emphasis is on high volume production of standardized components to reap benefits of economies of scale and division of labour; and build-up of inventories as 'buffer stocks' are kept just in case, to ensure a smooth production flow and to cope with rejected goods/ components. The problems associated with the JIC system are: the system is slow to respond to changes in market demand; inventories are expensive because of interest rate charges; there are high storage and maintenance costs; rejects and poor quality in general are concealed in buffer stocks; deep vertical hierarchy which usually leads to rigidity; workers' ability and knowledge are not fully utilized, and extreme specialization leads to problems of motivation, satisfaction, absenteeism and so on (Schonberger, 1982; Hall, 1983; Aggarwal, 1985).

The concept of the JIT manufacturing system is to produce and deliver finished goods just in time to be sold: sub-assemblies arrive just in time to be assembled into finished goods, fabricated parts just in time to go into sub-assemblies, and purchased materials just in time to be transformed into fabricated parts. Waste, defined as anything other than the minimum amount of equipment, materials, workers and time that are absolutely essential to production, should be eliminated, as it does not add value to the product (Low and Tan, 1997a,b).

For successful JIT implementation, techniques like waste elimination, Kanban or pull system, uninterrupted workflow, total quality control, employee involvement and long term supplier relations must be exercised. JIT helps to reduce inventory level, storage space, factory overheads, production costs and rectification works, and it leads to improvement in quality and productivity. On the other hand, the demerits of JIT are also particularly significant in the area of unexpected changes from the original plans. There could be sudden shortages of materials arising from sudden uncontrollable external factors like inclement weather and earthquakes (for example, the 1996 Kobe earthquake in Japan was blamed for disrupting many JIT production schedules). Thus JIT, being a highly regularized programme, could be badly affected and may be blamed for being inflexible, unresponsive, possibly disrupting of work flow, increasing production costs, open to sabotage from suppliers, and reducing quality standards. Nevertheless, there are three main manufacturing objectives associated with JIT (Suzaki, 1987). 1. increasing the organization's competitiveness in the long-run; 2. increasing productivity of the company; and 3. eliminating waste in materials, time and labour.

Application of JIT for site layout

The key element on JIT is 'stockless' production, i.e. reducing inventories in both raw materials and work-in-progress. Production in JIT is where everything is ordered, made and delivered just when it is needed. To achieve this goal, the JIT system is equipped with the following seven broad principles:

elimination of waste;
the 'kanban' or pull system;
uninterrupted work flow;

total quality control;
employee involvement;
supplier relations; and
continuous improvement.

Materials management is the management system that plans, acquires, stores, moves and controls materials in order to optimize all the company's resources (Magad and Amos, 1995). Therefore site layout is part and parcel of materials management as it determines the delivery of goods to the site, location of off-loading, location of the storage space, protection of the materials, and movement of materials to construction areas.

The site layout is a plan to determine where to locate items, be it plant, equipment or materials. Yet, the amount of planning that is required to achieve an optimum site layout best suited to the needs of the project and the on-site conditions is tremendous, especially when the site is constrained and the project period is short. Hence, JIT as applied within the context of site layout emphasizes managing materials storage and movement on site and the availability of mechanical plant and equipment required in the work process. Its objectives are to: 1. decrease the demand for site storage space and thus reduces holding cost; 2. group related activities on site based on the sequential process in handling the materials; 3. ensure that all plant, equipment and materials necessary for any activity arrive just in time for use; and 4. increase productivity through organizing the site to minimize movement as well as to allow easy handling of materials, plant and equipment to ensure smooth work flow. The applications of JIT concepts for site layout are discussed below.

Elimination of waste

The JIT approach to site layout is to eliminate all unnecessary stock on site and to decrease or minimize wastage on site. The effect would be a less cluttered working environment where less space on site would be required to hold buffer stock and hold rubbish bins. The resulting advantages would include a neater site with more space for workers to work in and clear space for mobile plant (for example, mobile cranes, forklifts and dumpers) to move about on site.

It is possible to use the prefabrication of repetitive components such as precast beams and columns, reinforcement bars and metal formwork to eliminate unnecessary inventory on site, thus leaving the site less cluttered. It would also facilitate better housekeeping as rubbish arising from excess concrete, leftover cuttings of reinforcement bars and packaging materials of cement is eliminated. Less timber and metal formwork is needed to be stored on site, thus decreasing the need to plan for space to hold such items. The schedule for use of plant and equipment on site should also be planned and expedited properly to ensure that there is little or no wastage of such a resource.

The kanban or pull system

The principles of the kanban or pull system is applicable in the context of construction materials management. Procurement of materials should be carried out at the right time and in quantities based on the actual demands on site (Monden, 1983; Low and Chan, 1996). For example, foremen in charge of structural works can feed back to the purchasing department the site requirements for concrete, reinforcement bars and formwork based on actual site conditions. Purchasing orders and/or delivery orders based on actual requirements on site (rather than schedules prepared much earlier in the project) can be issued to suppliers. This would eliminate the need to plan for storage space for excess inventory or stoppage of work due to lack of materials.

Uninterrupted work flow

The following two techniques may be used to achieve uninterrupted work flow.

Focused factory and group technology

An example would be to re-structure the site layout such that areas for stocking reinforcement bars, cutting and bending of rebars and fixing the steel are placed together to minimize movement and handling.

Simplification and automation

Work processes can be simplified by getting the job done right the first time. For example, the floor can be cast with drops as specified in the drawings to avoid future hacking or screeding of the floor before the tiles are laid. In Japan, robots have been used to execute construction tasks. Bar coding has been used to identify materials and prefabricated components so that electronically controlled robots or machines can bring them to the appropriate storage space and/or location for fixing. Such use of automation and technology would be an essential feature of an automated construction system (Lim and Low, 1992).

Total quality control

The goal is to get the job right the first time. If any problem is found at any stage of construction, it should be analysed and rectified at source. Every worker is personally responsible for the 'product' produced. The application of this principle in site layout emphasizes that the materials, plant and equipment supplied should be of good quality, and also ensure that everyone clears up rubbish at the source. With total quality control, work processes would flow smoothly, eliminating the wasteful and unnecessary movement of materials and plant on site to correct defects.

Employee involvement

JIT requires a flexible workforce that can perform multi-tasks, is innovative and is willing to take responsibility. To ensure successful application of the JIT concept, workers (both from the main contractor and subcontractor) must be:

- (i) taught the basic principles of waste elimination, operator's responsibility for performing work, zero defect quality and visibility management;
- (ii) trained to do multi-tasks on site. (e.g. the material handlers can be trained also to manage plant and equipment);
- (iii) encouraged to spot problems at source and solve them as well as be innovative in seeking better and less costly ways to do a job; and
- (iv) invited to participate in the traditional duties of top management such as in planning and organizing operations.

Supplier relations

Suppliers should be able to supply the right quantities at the right time to suit the client's production needs in JIT. This is directly applicable to site layout. In materials management, quantities of materials and time of delivery are suited to the actual consumption rate on site, materials should be in pallets or in other convenient form of handling methods, and materials should be unloaded at point of use. In plant management, the required mechanical plant must be on site when required and suppliers should maintain the plant periodically.

Continuous improvement

The five concepts of visibility management, to provide an environment for continuous improvement, can be applied directly to improve productivity through site layout in the following: (i) work processes are simplified to minimize the use of labour, plant and materials; (ii) site is neat and organized and allows, for example, easy transfer of materials to point of use; (iii) workers must be disciplined to adhere strictly to the principles of JIT; (iv) cleanliness on site is to be maintained by all personnel on site; and (v) workers participate in planning and organizing site activities and in problem solving.

The applications of JIT concepts for site layout can therefore be summarized as follows:

1. Construction process
   - (a) The contractor's programme can be used as a powerful tool to predict the sequence and timing of each activity undertaken by both the main contractor and subcontractors. This would allow for the proper scheduling of materials, plant and equipment required.
   - (b) Every worker should have a sense of responsibility to get his work done right first time. He should ensure minimal wastage of any kind while doing his work.
   - (c) Problems and defects should be analysed and solved at source to prevent wastage.
   - (d) Each worker makes it a point to clean up the work area after a job is completed.
2. Better materials management
   - (a) Materials should be ordered according to actual consumption on site and scheduled to arrive just in time before work begins.
   - (b) Materials should be packaged for easy handling and be unloaded at point of use.
   - (c) Every worker must be personally responsible for the materials they handle or use, to ensure as little wastage as possible.
3. Better plant management
   - (a) Plant and equipment usage is planned with respect to the contractor's programme and available just in time for use.
   - (b) Machines are maintained regularly to keep them in good working condition.
4. Proper site layout
   - (a) Site is planned properly and neatly to minimize unnecessary movements, handling of materials, plant and equipment and to ensure smooth work flow.
   - (b) Working place is properly organized, with tools and materials kept in designated places.
   - (c) Related activities on site are grouped together based on a sequential process for handling the materials.

Case study: Regent Heights Condominiums

The purpose of this case study is to examine how the JIT concepts have been applied to an actual construction project in Singapore to improve its site layout. The subject of this case study is the Regent Heights Condominiums at the junction of Bukit Batok East Avenue 2 and Avenue 5 (Figure 1). This development

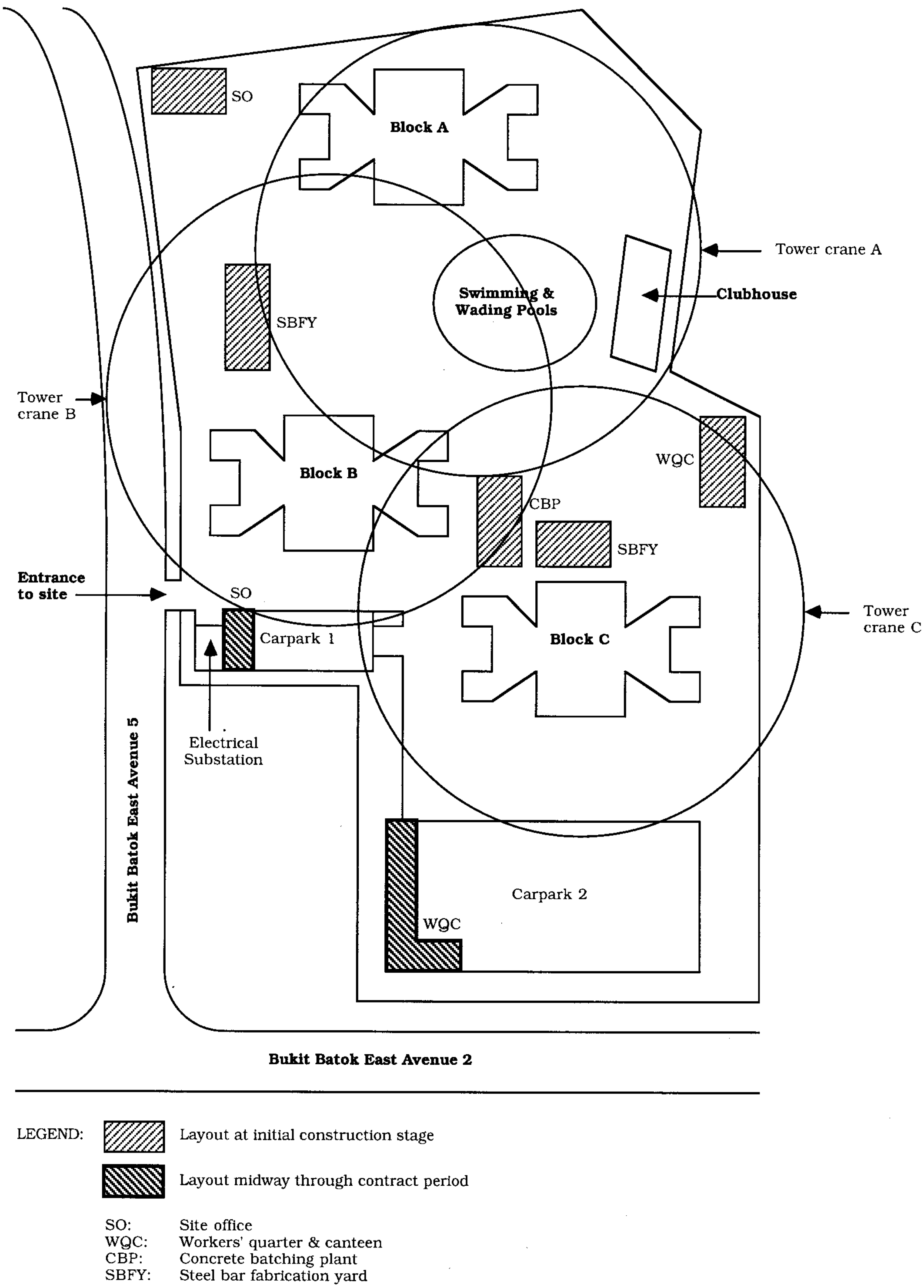

Figure 1 Schematic layout of site and tower cranes (not to scale)

consists of three 30–storey blocks of condominium apartments (with a total of 645 units), a single-storey carpark (carpark 1), a multi-storey carpark (carpark 2) and a clubhouse. Its recreational facilities include swimming and wading pools, a jacuzzi, an 18-metre long water slide, a golf-driving range, four tennis courts, garden pavilions with barbecue pits and a basketball court. The site covers an estimated area of 27 034 m^2, the total gross floor area of the project is 75 089 m^2 and the construction period was 100 weeks beginning 18th October 1996 and ending 17th September 1998. The contract calls for two specific handover dates for the electrical substation (ESS) and four mock-up units at Block A.

The main contractor for this project is Neo Corporation, a general building contractor registered with the Construction Industry Development Board, Singapore in the G8 category. (Note: there are eight categories of contractor registration in Singapore. These range from G1, the smallest category, to G8, the largest category.) The managing director of Neo Corporation, a chartered builder, strives for continuous improvement within his organization. Neo Corporation was among the first few construction firms in Singapore who achieved certification to ISO 9002 for its quality management system. It is presently developing and implementing an environmental management system to meet ISO 14000 requirements. As part of his continuous improvement programme, the managing director also encourages his employees to strive for higher productivity in Neo Corporation's construction projects, including the overt application of JIT concepts for site operations. To achieve this objective, books and articles on JIT as applied in construction were purchased by the managing director for compulsory reading by all his senior managers. In this case, the Regent Heights Condominiums project is no exception. The project manager for Regent Heights Condominiums was encouraged to understand and conscientiously apply JIT concepts, where appropriate, to raise productivity and quality standards. The application of these concepts in the project are examined below.

Site organization

Due to the scale of the project, the project manager divided the entire site into three working zones, each headed by a block manager (Figure 2). The details of the site organization chart and duties of staff members are explained below.

The construction team

Zone A consists of Tower Block A, the clubhouse and the major part of the swimming pool; Zone B consists of Tower Block B, the single-storey carpark, a golf driving range and the entrance to the condominium; Zone C consists of Tower Block C, the rest of the swimming pool, the multi-storey carpark, four tennis courts and a basketball court. In addition, block managers were in charge of all external works that fell within their respective zones. As Zone C covers a much larger area of work than the other zones, two engineers were deployed to work under the block manager for the Zone, one in-charge of the Tower Block, and the other in-charge of carpark 2 plus other external works.

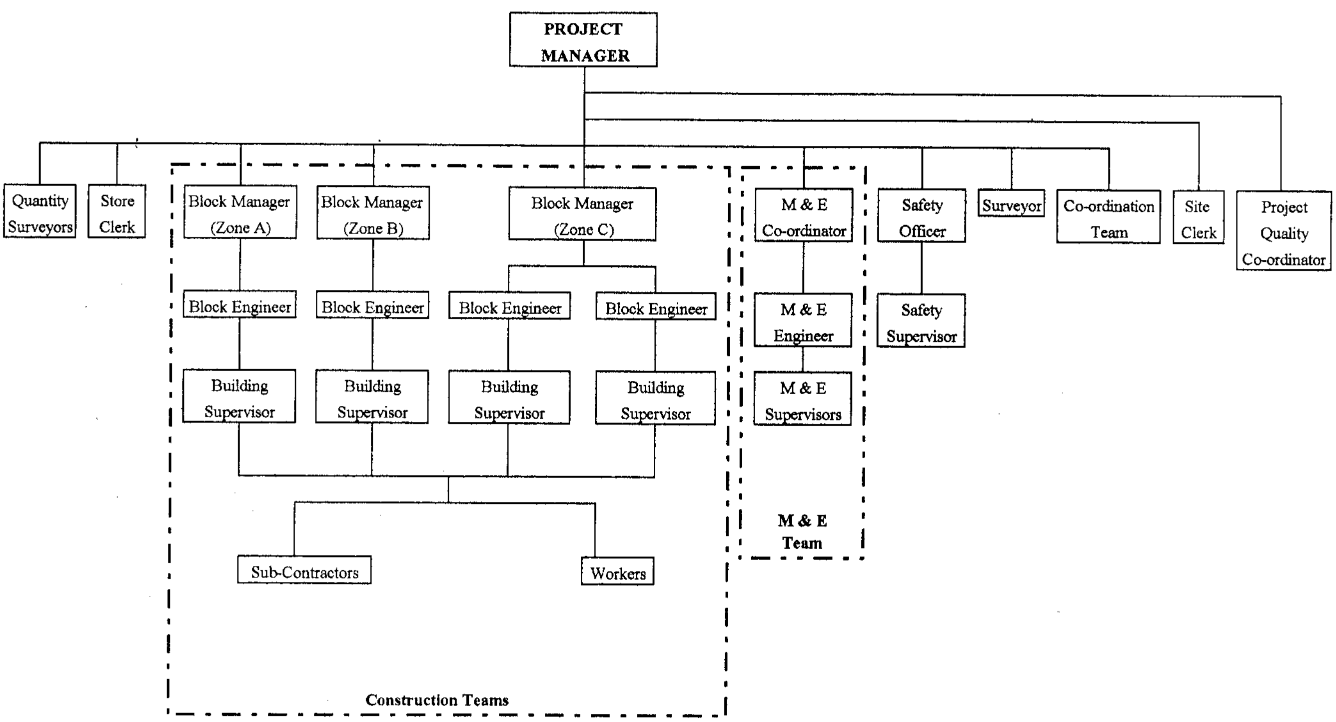

Figure 2 Site organization chart

The M&E team

The M&E team was small compared with the construction team. This is because it was a relatively new department in Neo Corporation and most M&E work is subcontracted. An M&E engineer and supervisor was assigned to each of the zones to assist the block managers in the supervision of M&E subcontractors.

The coordination team

This team coordinated all the architectural, structural, mechanical and electrical details in the project and sought to clarify with the consultants should any discrepancy occur. They also produced the as-built drawings for the site.

The material handling team

The staff responsible for the control of materials on site were the site quantity surveyors, the store clerk and the block managers. Materials that are not part of the contract (for example, safety boots and helmets, tools for workers like screwdrivers, etc.) and materials required for every site (for example, concrete, reinforcement bars, bricks, etc.) were ordered through purchasers at the head office. Contractual materials (like tiles, water-heaters, timber doors and windows, etc.) were procured by the site quantity surveyors.

The project quality coordinator

Neo Corporation obtained ISO 9002 certification in 1994. It is a requirement for ISO certification to have a project quality coordinator to ensure that all construction activities are carried out according to procedures and guidelines stated in the company's quality manual, and to seek ways for improving the quality of work on site. The certification implies that the company is committed to producing quality buildings that satisfy the client's needs, efficiently. As mentioned above, Neo Corporation also used Regent Heights Condominiums as a pioneer site for the development and implementation of an environmental management system which meets the requirements of ISO 14000. This shows that the company is committed to elimination of waste – another basic principle of the JIT concept.

Mechanized equipment

Neo Corporation has a plant division which supplies all its site with mechanical plant. These were ordered through the block managers or the project manager.

Planning for the project

Planning for the project falls under two categories, namely the contractor's programme and site layout.

Contractor's programme

There were essentially four types of programmes planned: 1. a general programme which stated all major activities in the project and was produced during the initial stages of construction; 2. a detailed structural programme expanded from the general programme when construction began and given to all site staff and consultants; 3. bi-weekly programmes for structural works that were issued to all staff and relevant subcontractors; and 4. an architectural programme, which also included time for procurement and fabrication of some critical items, issued to all site staff and all architectural subcontractors/suppliers. These programmes were reviewed regularly and adjusted according to actual site conditions. Changes were then disseminated to all relevant staff, subcontractors and suppliers.

Site layout

The site layout and tower crane layout are shown schematically in Figure 1. It should be noted that the site is constrained. Therefore, the site office and the workers' quarters had to be shifted mid-way through the project to make way for external works. The rationale for such a site layout is discussed in greater detail later.

Elimination of waste

The types of waste commonly found in the manufacturing production lines were examined to see how JIT principles could be applied to improve site layout for Regent Heights Condominiums.

Waste from overproduction

The materials fabricated on site were: system formwork used in the construction of the shear walls (for the lift shaft and the staircase shaft) in the tower blocks and metal formwork used for all columns in the project; table formwork for the construction of floor slabs in the tower blocks and carpark 2; timber formwork; and reinforcement bars. The amounts of system, metal and table formwork fabricated for use were just enough for one concreting operation within each zone. They were fabricated at the beginning of construction of such elements and reused for all 30 storeys of the tower blocks and 13 decks of carpark 2. As these were fabricated at the point of use, there was no possibility of overproduction for such items.

Timber formwork essentially was used to construct surface channels and in other places where it was uneconomical to use metal formwork. All the timber formwork was fabricated at the point of use, where the exact sizes of each piece of formwork were measured. Each carpenter was assigned to fabricate a particular section, thus further minimizing the possibility of overproduction.

Reinforcement bars that required special bending and/or cutting were fabricated at the two fabrication yards on site (Figure 1). The exact number and length of each reinforcement bar were calculated by the reinforcement bar subcontractors. To ensure that the subcontractors did not over-produce, block managers and engineers conducted regular spot-checks, site quantity surveyors paid the subcontractors according to the amount measured from the as-built drawings produced by the coordination team (Figure 2), and a fixed percentage of waste was allocated during the award of the subcontract.

Waiting time

All the programmes described above gave an exact time frame to each and every activity in terms of the start and finish dates, and the bi-weekly schedule gave the exact timing, accurate to the hour, to each activity. The schedules were passed to the relevant persons described above. The programmes were then used by site quantity surveyors, block managers and/or the project manager to procure and schedule deliveries of resources (materials, plant and equipment) required for any type of work, block engineers to plan the tower crane or other plant usage, and supervisors of main contractor to plan the work of their workers for the subsequent day. With these measures, there was seldom a need to wait unnecessarily for people to finish their part of the work, for undelivered materials, for the mechanical plant to be available, etc. and thus work proceeded smoothly. Should any changes be made to the planned schedule, the main contractor's staff also made it a point to communicate immediately to the relevant subcontractors or suppliers.

Transportation waste and waste of motion

Materials required daily, such as bricks and thermalite or autoclaved aerated concrete blocks were delivered to site every day and unloaded at points of use. Buffer stock was stored in the temporary holding areas, where they remained for not more than two days. Therefore the maximum number of times of handling any such materials was two: once when the goods were delivered to the temporary storage area and then for transporting to the point of use. The tower cranes were placed so that their jibs covered the entire block and the access roads around the block (Figure 1). Supplier trucks accessed the blocks via the access roads for materials to be delivered to the point of use. The concrete batching plant was placed at the centre of the site allowing concrete to be delivered through concrete trucks to the point of usage as quickly as possible. The two reinforcement fabricating yards (one catering to Blocks A and B and carpark 1, the other catering to Block C and carpark 2) were within reach of the tower cranes. Reinforcement bars also were stored next to the fabrication yard.

Inventory waste

Materials, even when ordered in large quantities, were delivered in small lots to the construction site as and when required. This is discussed in greater detail later.

Waste for product defects

One of the main contractor's company policies is to get the work done right the first time. Therefore, e.g. before any concreting was carried out, the plumb lines, the levels of the floor slab, the depth of drops, the location of cast *in-situ* pipe fittings, etc. were checked. Hacking of concrete due to mistakes on the part of the main contractor's staff and subcontractors was frowned upon. In some cases, subcontractors were fined and made to pay for the cost of hacking and making good due to mistakes on their part.

Reuse of materials to decrease the amount of waste on site

The main contractor aimed to minimize waste by reducing the use of materials that contribute significantly to waste and reusing as much of the 'waste' as possible. For example, the use of timber as formwork often contributes to the bulk of the waste on a construction site. In this project, there was a conscious effort on the part of the main contractor to replace timber formwork with metal formwork. Concreting on site is usually done by concrete pumps. Instead of throwing away the concrete left in the pipes of the concrete pump, it was used to fabricate lintels (placed over doors and windows) and also road kerbs.

The kanban or pull system

The various contractor's programmes discussed above served as guidelines to allow the material handling team and the suppliers to plan for the delivery of goods. The pull system acted as the main force for the fabrication of reinforcement bars/formwork and the delivery of goods to site. Materials were fabricated/delivered to site only when ordered or when the stocks were dropping below the minimal stock requirements. The pull system therefore decreased the demand for site storage space and reduced holding costs.

Uninterrupted work flow

The following issues were addressed to achieve uninterrupted work flow in the Regent Heights Condominiums project.

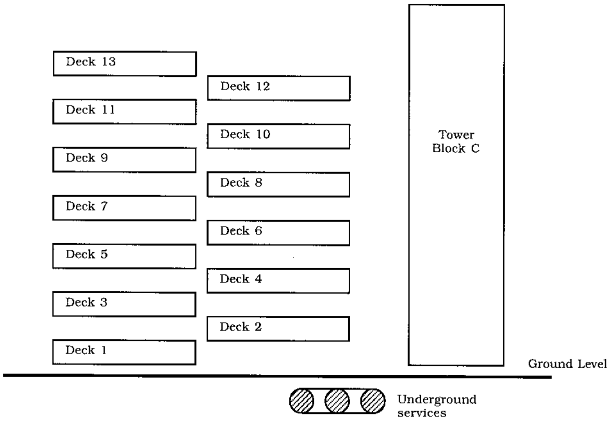

Figure 3 Cross-section of carpark 2

Simplification of work

A good example in this case study was the alternative structural design proposed by the main contractor. This alternative design decreased the deadload of the building with the use of lightweight materials like thermalite walls and plasterboard instead of brickwall with plaster and paint. It simplified by streamlining the complex structural design to the bare minimum, facilitated the use of table formwork, and enabled the main contractor to achieve a floor-to-floor cycle of nine to ten days.

Construction sequence

The construction sequence in the case study was thought out carefully to ensure uninterrupted work flow. An example of uninterrupted work flow concerns the construction sequence of carpark 2 (Figure 3). If it were built in the conventional manner (i.e. deck 1 followed by deck 2, 3 and so on), the construction of underground services and Block C's entrance would be disrupted. To overcome this problem, the odd decks were constructed first, thus leaving the area free for the construction of underground services and Block C's entrance. After these were completed, the even decks were built.

Availability of materials

The work flow in this case study which concerns the availability of materials was also thought out carefully. For example, there were many tiles used in this project which had to be shipped in from Italy, the Philippines, India and China. In view of the client's request for early completion of the clubhouse, swimming pool and four mock-up units in Block A, the block managers and site quantity surveyors had to ensure that the appropriate tiles required for these areas were delivered in time for the tilers to use. In preparing the schedule of procurement and delivery of goods, the following factors were considered: time needed to source and to call for quotations from various suppliers; time required for the shortlisted suppliers to prepare samples for the client and architect to select from; time lapse before the client and architect approved and confirmed the samples; time needed to ship the materials from overseas; travelling time from the supplier's warehouse to the site; and storage space on site (this included the space available for storage and the protection of these materials from pilferage). Usually, most materials imported from overseas have to be ordered in terms of number of containers. Frequently, this creates a problem as the amount of material required for one single operation usually does not fill one container. The arrangement which the main contractor made with the supplier was to give the supplier the total amount of tiles required for the entire project plus a projected schedule of the amount of materials (enough for one single operation with wastage allowance) to be delivered to site on a certain day. The supplier then shipped in the goods by the container load, delivered the required quantity and held on to the excess quantities. This arrangement helped to decrease the demand for site storage space.

Availability of plant

In the Regent Heights Condominiums project, plant and equipment were checked regularly to ensure that they are in good working condition at all times.

Site layout

A major concern during the planning of the site layout was to ensure that construction could go on uninterrupted because the contract period is relatively short. Thus, the site layout was planned to cater to this concern. The site layout plan includes a consideration of the following items.

Site office Originally, the project manager wanted to locate the site office beside carpark 1, next to the electrical substation, because this location affords the longest period of stay for the site office. However, locating the site office there would have inconvenienced work to the electrical substation, which had to be handed over early to the client. To avoid interrupting the work to the electrical substation in carpark 1, the site office was located initially at the left upper corner of the site and subsequently shifted to carpark 1 when works there were completed (Figure 1).

Tower crane layout All tower cranes used in the project were luffing cranes. The tower crane for Block A was located one gridline nearer to the edge of the block compared with that in Blocks B and C. This facilitated the construction of the pool-deck as requested by the client. Also there was no stationary tower crane to cater to carpark 2 because the span of the luffing jib of the tower crane did not cover carpark 2 entirely, the Building Authority in Singapore did not allow the use of a straight boom tower crane as the boom would then extend out over public roads, and it would have been uneconomical to use when a mobile crane would be cheaper.

Workers' quarters The project manager was forced to place the workers' quarters as indicated on Figure 1 initially even though it tended to obstruct some work towards the end of the contract period because there was no place that was large enough to house the workers' quarters and the canteen, and by the time the minor external works were done, carpark 2 had been completed. The quarters were then shifted there.

Site batching plant The site batching plant was placed at a central location because it caused least obstruction and therefore did not interrupt work flow, there was minimal movement of concrete trucks, and it was near the site access to facilitate the delivery of raw materials to site.

Steel reinforcement fabrication yard There were two rebar fabrication yards (Figure 1), one for Blocks A and B, and the other for Block C and carpark 2. These were placed within reach of the respective tower cranes for the block and positioned such that reinforcement bars could be stored next to the prefabrication yard. Also, these locations were not needed during the structural stage of construction.

Total quality control concept

As Neo Corporation has obtained ISO 9002 certification, quality assurance is very much part of its corporate culture. The application of this concept means that problems are solved at source, and getting the job right the first time. For example, casting the floor slab with the actual drop requirements eliminates the need to hack or screed the floor before the laying of tiles. This concept, when applied to site layout, ensures that materials supplied are of good quality, and that everybody clears up rubbish at the source.

Employee involvement and continuous improvement

In Neo Corporation, employees were given the liberty to make decisions within their own scope of work immediately, so as not to hold up the works further. They were encouraged to solve problems at the lowest possible level of the organizational hierarchy. Problems were brought up to the next level only if they could not be solved at the lower level. Employees were actively involved with seeking more efficient and effective ways to complete a job. In the Regent Heights Condominiums project, suggestions for improvement frequently were brought up to the project manager or block managers for approval.

Supplier and client relations

The main contractor in the case study strictly enforced the rule that suppliers would deliver the goods only when they are asked to. They were not allowed to use the site as a storage space for the goods. This eliminated the need to store and protect buffer stock.

Discussion

The purpose of this case study is to examine how the seven JIT concepts have been applied explicitly to an actual site to improve its site layout effectively. These seven concepts are elimination of waste, the 'kanban'/pull system, uninterrupted work flow, total quality control, employee involvement, supplier relations, and continuous improvement. As can be seen from the case study, it is possible to apply the various JIT techniques for site layout to improve productivity. It also may be noted from the case study that the main difficulties in the implementation of JIT are people-related problems. JIT is only a philosophy, a method of achieving high productivity and quality with little or no wastage. Without a cooperative workforce, its implementation would reap none of the benefits experienced in the manufacturing industry. With this in mind, there are four groups of people to consider before JIT can be implemented successfully in the construction industry: clients/consultants, suppliers, subcontractors and workers.

Clients and consultants

The use of standard components in prefabrication, which mirrors the repetitive processes found in the manufacturing industry, would facilitate the application of JIT concepts. The difficulties, however, are that (i) the consultants may not have the knowledge or ability to design a building using such standard components that is pleasing to the client both aesthetically and functionally, and (ii) the client usually does not want his building to look like everybody else's buildings. He would rather sacrifice buildability for a more aesthetic and unique building.

Suppliers

Suppliers may not be able to adapt quickly enough to cater to the main contractor's requests for delivering small lot sizes frequently, especially if the company has yet to adopt the JIT principles. Furthermore, developing a long term and trusted relationship with a single supplier who is able to cater for all the needs of the company takes a very long time, numerous meetings, committees and staff other than those in the purchasing department (Westbrook, 1988).

Subcontractors

Subcontractors play a very important role in a construction project as they make up for the lack of manpower, technical know-how, etc., of the main contractor. Essentially, subcontractors are needed to carry out most if not all of the works on site. Subcontractors need to be educated in JIT and be guided along during the entire construction process. It is no use having only the main contractor's staff practising JIT concepts. However, it would take time for the subcontractors' workers to be educated and trained.

Workers

Most of the labour employed in the construction industry in Singapore comes from foreign countries. Communication barriers and cultural differences may make the education process difficult. JIT also involves training workers to be multi-task workers. These foreign workers normally have a maximum of four years' stay in Singapore, and hence there is some impracticality.

However, in spite of these hurdles, there are benefits to be reaped by a conscious attempt to harness JIT concepts on site. In re-engineering its operations along the lines espoused in the JIT philosophy, Neo Corporation was able to achieve cost savings in terms of materials and labour in the following two items.

Revised subcontracting system

Neo Corporation maintains a pool of its own skilled workers who are seconded to its subcontractors to undertake work critical to a project's progress. Carpenters, for example, are loaned to the formwork subcontractor to ensure that work is completed on time, quality is maintained and wastage minimized to 5% (CIDB, 1998).

Training multi-skilled workers

The company believes not only in using skilled workers but also in multi-skilled workers. A group of 8 or 9 multi-skilled workers is deployed by Neo Corporation to undertake tasks such as installing formwork, laying precision blocks, installing plasterboard linings and door/window frames. In the French School project in Singapore, only 44 workers were needed on site. Arising from this, there was a 50% labour saving compared with similar projects built using conventional methods by Neo Corporation. Also, the French School project was expected to be completed three months ahead of its original schedule (CIDB, 1998).

Conclusion

Although it is difficult to differentiate between site layout benefits derived from JIT and good project management practices in the Regent Heights Condominiums case study, the observations noted from site visits seem to suggest that there was a conscious and premeditated attempt on the part of site personnel to apply JIT concepts in their sphere of work. Admittedly, this paper is only an attempt to demonstrate how the seven JIT principles were operationalized on a building project for site layout. As JIT in construction is an area of work which is still in its infancy, the following two recommendations are suggested for further research.

1. Establish the differences in performance (in terms of time, cost, quality and the environment) between similar building projects which have implemented JIT concepts and those which have not.
2. One of the key objectives of JIT is to reduce inventory costs. The reduction in inventory costs, with its consequential effects on cash flow, is recommended for further research.

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References

Aggarwal, S.C. (1985) MRP, JIT, OPT, FMS? Making sense of production operation systems. *Harvard Business Review*. September/October, 8–16.

Cheng, T.C.E. and Podolsky, S. (1993) *Just-in-Time Manufacturing: An Introduction*, Chapman and Hall, London.

CIDB (1998) Local contractor re-engineers operations to achieve superior construction performance, in *Construction Focus,* Vol.10, No.3, Construction Industry Development Board (CIDB), Singapore, pp.4–5.

Hall, R. (1983) *Zero Inventories*, American Production and Inventory Control Society and Dow Jones-Irwin.

Lim, L.Y. and Low, S.P. (1992) *Just-in-Time Productivity in Construction*, SNP Publishers, Singapore.

Low, S.P. and Chan, R.Y.M. (1996) The application of just-in-time principles to process layout for precast concrete production. *Singapore Management Review*, **18**(2), 23–39.

Low, S.P. and Tan, K.L. (1997a) The measurement of 'just-in-time' wastages for a public housing project in Singapore *Building Research and Information*, **25**(2), 67–81.

Low, S.P. and Tan, K.L. (1997b) Quantifying just-in-time wastages for a design-and-build school project. *Journal of Real Estate and Construction*, **7**(1), 70–91.

Magad, E.L. and Amos, J.M. (1995) *Total Materials Management: Achieving Maximum Profits Through Materials/Logistics Operations*, 2nd Edn, Chapman & Hall, London.

Monden, Y. (1983) *Toyota Production System: A Practical Approach to Production Management*, Institute of Industrial Engineering, Norcoss, GA.

Mortimer, J. (1986) *Just-in-Time: An Executive Briefing*, IFS Publications.

Schonberger, R.J. (1982) *Japanese Manufacturing Techniques – Nine Hidden Lessons in Simplicity*, The Free Press, New York.

Suzaki, K. (1987) *The New Manufacturing Challenge*, The Free Press, New York.

Voss, C.A. (1987) *Just-in-Time Manufacture*, IFS Publications.

Westbrook, R. (1988) Time to Forget 'just-in-time'? Observations on a visit to Japan. *International Journal of Operations & Production Management*, **8**(4), 5–21.