Concurrent Construction and Life Cycle Project Management

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Abstract: This paper investigates "concurrent construction" and its potential application in life cycle management of capital projects. The construction industry is under pressure to reduce project delivery times and costs despite increased uncertainties, ambiguities, and complexities that surround today's projects. Concurrent construction may well hold the key to success on this front. Concurrent construction is based on integrating all project phases into a single phase. It starts with the definition of a product model and division of the project into major parts or systems accordingly. Each part or system is entrusted to a team consisting of members drawn from the relevant disciplines as well as the contractor. The delivery of a specific part is carried out by the relevant team in an integrated fashion in a single phase. While the potential benefits of concurrent construction are beyond doubt, current contractual, organizational, and work method barriers militate against realizing these. However, there are workable solutions to these problems. This paper covers examples of approaches that could overcome these barriers.

INTRODUCTION

This paper addresses "concurrent construction" in the context of total life cycle management of capital projects. A discussion on the origin of "concurrency" and its relevance to construction and project management leads to a more detailed definition of this approach, including its practical application considering uncertainties and the dynamic nature of capital projects. The paper then presents a framework for implementation of concurrent construction, incorporating a unified project information base and a proactive integrated project management system. "Proactivity" has a specific meaning in the context of concurrent construction and relates to a set of objective functions that aim to maximize project value. The paper also looks at the contractual framework for successful application of concurrent construction to capital projects.

The need for reform in the construction industry is acute. The industry is under pressure for change worldwide, and must undergo further organizational, structural, and cultural transformations. The Construction Round Table, which is an association of a group of large owners, has set for itself the target of reducing construction costs by a third without compromising quality or standards. This body has issued a charter for fair dealing in the construction industry. Cost Reduction In a New Era (CRINE), an initiative formed in the United Kingdom has similar aims for cost reduction in the engineering construction industry, through collaborative and alliance-type arrangements. Similar pressures have been felt in the Australian construction industry ("Construction Industry" 1991). Recently, instances of success through collaborative work and the resulting project changes have been reported, including Glasgow Airport extension and the St. Andrews field in the North Sea (Turner 1996).

There are thus real opportunities to achieve major process efficiencies and savings on actual costs and delivery times on constructed facilities. However, this task should not be seen as relevant to the contracting industry only; rather, it is a task for the entire construction industry, including the design and consulting professions, owner groups, the construction research and education community, governments, and other stakeholders. Concurrent construction may provide an impetus to embrace new working philosophies in the construction industry.

WHAT IS CONCURRENT CONSTRUCTION?

Concurrent construction (CC) may be defined as an integrated approach to the planning and execution of all project activities, from the conceptualization state through to the handover of the facility. It seems to be a new term, derived from an extension of concurrent engineering (CE). The concept of integrated design and construction is by no means new in the construction industry, as similar terms and techniques have been around in one form or another for some time, responding to the time and cost pressures on capital projects. For example, the engineering, procurement, and construction management (EPCM) method has been around for many years in the engineering construction industry. A new method of risk-sharing and partnering, known as project alliance method, has also been developed and used widely [see Jaafari (1996a); Haugstad (1996); Hetland (1996)]. In the building industry, fast track, design-and-build, construction management, and similar methods of project delivery have been practiced widely in recent years, with varying degrees of success (Newcombe 1996; Love and Gunasekaran, in press, 1997). However, there seems to be a new emphasis on further shortening the project delivery timescale and eliminating unnecessary activities as far as possible.

Concurrent construction must not be confused with fast tracking. In the fast track method the project is still executed in a phased manner except that design and construction activities are merely overlapped to save time. This practice is claimed to cause suboptimal design, cost and time overruns, lack of teamwork between designers and contractor, and other problems (Love and Gunasekaran, in press, 1997). Under concurrent construction, all project activities are integrated and all aspects of design, construction, and operation are concurrently planned to maximize the value of objective functions while optimizing constructibility, operability and safety.

WHAT IS CONCURRENT ENGINEERING?

Concurrent engineering has its origins in the manufacturing industry, where it has been used beneficially to shorten the product development cycle (Shtub et al. 1994; Carter and Baker 1992; Kusiak 1993). There are two views on concurrent engineering in the manufacturing sector. The first view, advocated by the early pioneers of CE, is that the engineering and design phase in product development often in-

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volves a series of activities, traditionally executed by different functional departments in a phased, sequential approach. As far as possible, these activities should be clustered, integrated and managed concurrently, rather than sequentially, to save time (Shtub et al. 1994; Clark and Fujimoto 1989).

The second view sees the engineering and design phase as just one aspect of developing and launching a new product, and targets all aspects, such as concept creation, market research, procurement, creation of sales and service networks, and other activities. Lautier (1996) states that these nonengineering activities may be more critical and consume more resources than the engineering part alone. He cites three reasons for adopting what he refers to as a concurrent project management approach (CPMA): (1) The rate of return on investment is lower when the project cash flow is stretched; (2) delays in projects will normally translate into increased costs since resource utilization will be affected; and (3) the market price of new products tends to decrease with time because competition will increase with time.

CONCURRENT CONSTRUCTION OBJECTIVES

The main objective of concurrent construction is to install a system of project management that will drive the entire project over its life cycle proactively, in a manner that capitalizes on opportunities while steering the project clear of the constraints it faces. Proactivity must be related to the achievement of project objectives. Under concurrent construction, in addition to the normal objective functions such as project cost, time, quality, and performance, it will be necessary to define life cycle objective functions, namely, total life cycle cost (TLCC), cost/worth ratio, internal rate of return (IRR), and present value or profitability index (defined as the net present value divided by the total capital cost), as the basis of proactivity and for measuring the success of the concurrent construction approach in adding value to the project continuously. Target values set for these functions will act as the guiding goals for assessing all design and construction decisions, including the value or impact of changes made to the project during its implementation. The same target values, vis-à-vis actual values achieved on completion, can form a basis for incentive-based contractual arrangements for regulating owner-contractor collaboration and for motivating project participants (Jaafari 1996a).

APPROACH TO CONCURRENT CONSTRUCTION

Concurrent construction is based on

- Integration of all project phases into a single phase
- Simultaneous inclusion of the relevant information on engineering, design, approval, manufacturing, construction, commissioning, and operation
- Formation of composite teams, having a representative from each of the pertinent parties, including architect, engineers, manufacturers, constructor, operator, and facility manager. In some cases, representatives of governments and statutory authorities may also be considered
- Division of the work into separable parts and allocation of each to a single composite team
- Proactive management of the project and its parts on the basis of planning, staging and managing all project activities continuously to optimize the objective functions already described
- Integration of total project information over its life cycle
- Integration of the work of the teams into a single project
- Establishment of direct and real-time intra- and interteam communication systems to facilitate the whole process

WORK AND RESPONSIBILITY ALLOCATION

Development of an integrated work breakdown structure is a key requirement in the CC approach. Activities with high affinity to each other must be clustered and managed as an integrated undertaking in order to expedite the project processes. For example, activities representing the design, procurement, and operation of a cooling tower in a process plant may show high interdependency and should be considered as a distinct cluster to be assigned to a dedicated team. How can clustering of activities be organized in a manner that makes concurrent construction effective?

Hanssen and Schellekens (1996) define a technique for developing what they term the "partitioned dependencies matrix," from which clustering of the activities may be contemplated. This technique enables the division of the project into separable parts; each part is then linked to the relevant cluster of activities which will define design and manufacture of that part. The criteria they suggest for measuring the success of the above process are:

- The total number or percentage of information exchanges between clusters
- The number of daily information exchanges between clusters
- The number or percentage of risky information exchanges between clusters (a risky information transfer is a transfer in which an inadequate information transfer during project execution leads to considerable extra work

In a successful clustering the number or percentage of information exchanges between clusters will be at a minimum and the risky exchanges between the clusters will be defined and rigorously managed to avoid the risk of extra work due to possible communication failures.

There is no doubt that adoption of a work breakdown structure that aims at integrating teams with project parts is more rational than the traditional sequential approach to design, procurement, construction, and handover. For example, instead of lumping all design activities related to all parts of a project together and treating these as the design phase, it will be possible to divide these into clusters, each referring to a particular part of the project. Clusters can be enlarged to include the relevant front-end activities as well as downstream procurement and construction activities. Each cluster can be assigned to a team and executed in an integrated fashion. In this way users' requirements, safety and statutory issues, product manufacturers' and constructors' views, and other inputs are all brought to bear simultaneously on the part under consideration, thus avoiding or reducing future revisions and reworks and, at the same time, eliminating unnecessary activities that would result under a phased project management approach. (The delays and unnecessary activities are partly due to indirect, time-lagged, multi-layered communication processes, multiple data entries, and numerous avoidable revisions, as well as organizational and managerial structures set up to manage each phase separately under most phased project management approaches).

In addition to the above benefits, the main advantage of this approach is the potential for adoption of a proactive, value-driven management approach, i.e., an ability to drive the relevant cluster of activities proactively in order to add value or to optimize other objective functions already referred to for the part or system under consideration, albeit within the overall project framework.

The success of the integrated team and part approach will depend on the success achieved in maintaining and enhancing the integrity of the project throughout its implementation period and on how well the clusters eventually come together to

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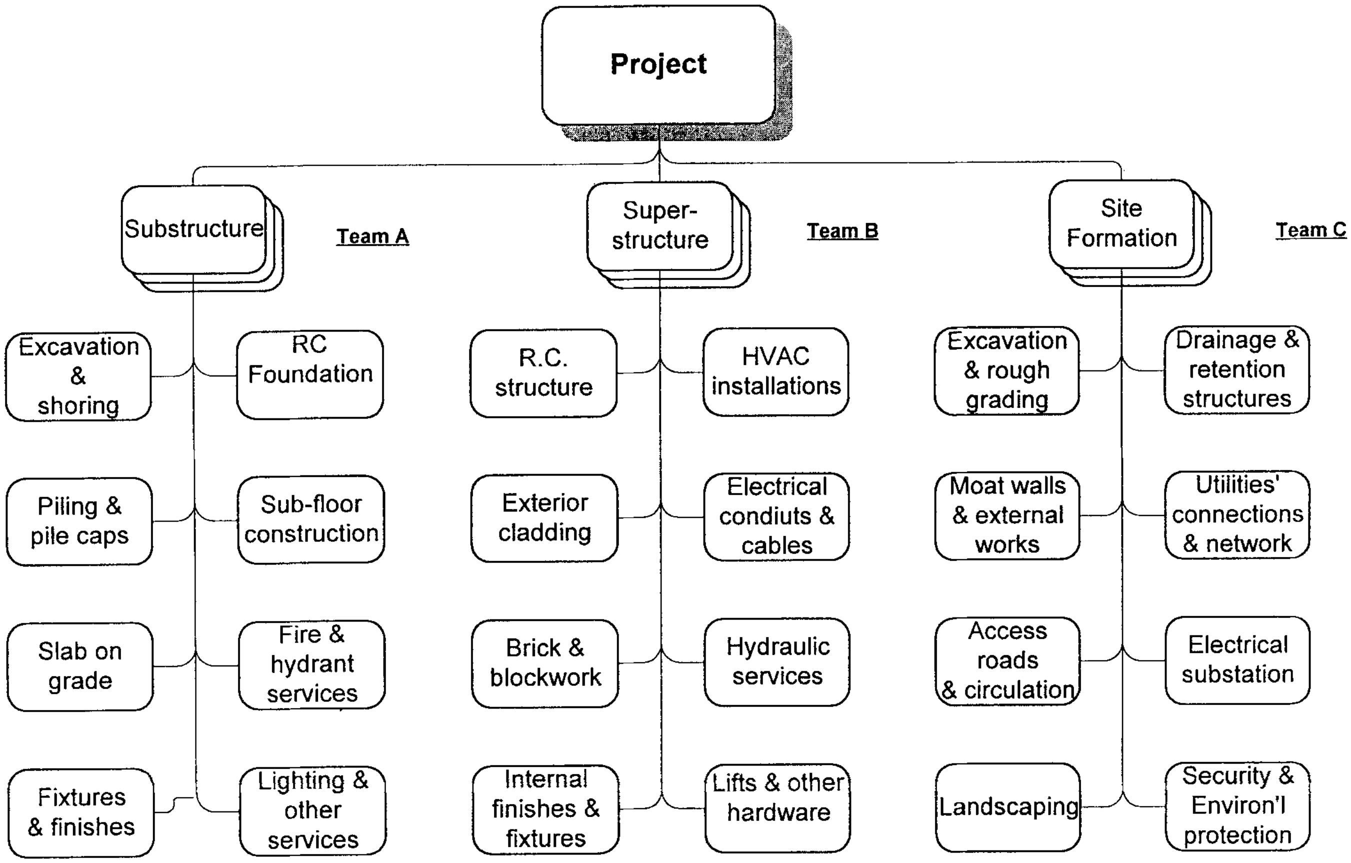

FIG. 1. Schematic Representation of Clustering of Activities in Concurrent Construction

form the complete project. A thorough configuration management approach, a sharing of common information, and facilitation of real-time communication are linchpins for the success of this process.

Communication plays a major part. To create focus for multiparty communication it is necessary to use an agreed initial configuration or a product model for the project. While this may change over the implementation period, its development at the conceptual state will provide a common understanding of the project, including its intended objectives and functions. Once there is a common understanding of the project and its objectives, it will be possible to develop the activities spanning its entire implementation period. These activities will be grouped into clusters, and one or more clusters may be assigned to a composite team. To save time, the implementation of the project may be planned in a manner that facilitates parallel execution of the clusters.

Fig. 1 demonstrates schematically the clustering and integrated team concept for a medium-sized building project. Essentially, the example project is divided into three parts: substructure, superstructure, and site formation. If desired, it would be possible to include additional clusters relating to activities other than design and construction, such as legal and financial matters, marketing and sales, and so on. Should the project be small (such as a single dwelling) there will be a single cluster for all activities including site formation and sub- and superstructure. For larger, multi-unit projects, more than three clusters may be considered, depending on the way the work is desired to be organized and the time pressure to which the project is subjected.

For each cluster it is assumed that a team will have total responsibility. The team will include members from all the relevant disciplines as well as representatives from the relevant authorities, users (tenants and/or the building owner), the contractor, specialist subcontractors, and manufacturers of the constituent systems and components. In this manner the views of the downstream players are integrated into design decisions at an early stage, and the project is designed not only for constructibility and optimum operability but also for eventual recycling or demolition. The coordination and integration of the parts (clusters) into a single configuration is effected at project level through configuration management as well as through lateral communication between teams (see Fig. 2).

It is worth mentioning that under the partitioned dependency matrix technique (Hanssen and Schellekens 1996), certain activities may end up being clustered together regardless of the project parts to which they belong. Also, certain activities may end up being necessarily executed in a sequential format. Examples include certain design activities in which the execution of one activity may be dependent on the completion of its predecessor. Under the aforementioned technique, the criterion for clustering is the extent of dependencies that exist among activities, not where the activities originate. Obviously this style of clustering may cause more confusion when it comes to the allocation of responsibilities on construction projects. The reason is that the construction industry has been accustomed to contractual packaging of works in accordance with discipline or trades specialization, not the extent of interdependency among a group of activities.

Will this approach save time and reduce unnecessary activities in the total design and construction (or total development) process? There is no hard evidence to suggest that this will be the case. However, there are reports of the potential savings to be made, e.g., Love and Gunasekaran (in press, 1997) cite that through the application of concurrent construction it will be possible to achieve 25% savings on the overall project duration without additional resources. Mohamad and Yates (1995) report that from the end users' perspective, an investigation has shown that unnecessary activities may consume up to 40% of the project duration, from inception to handover

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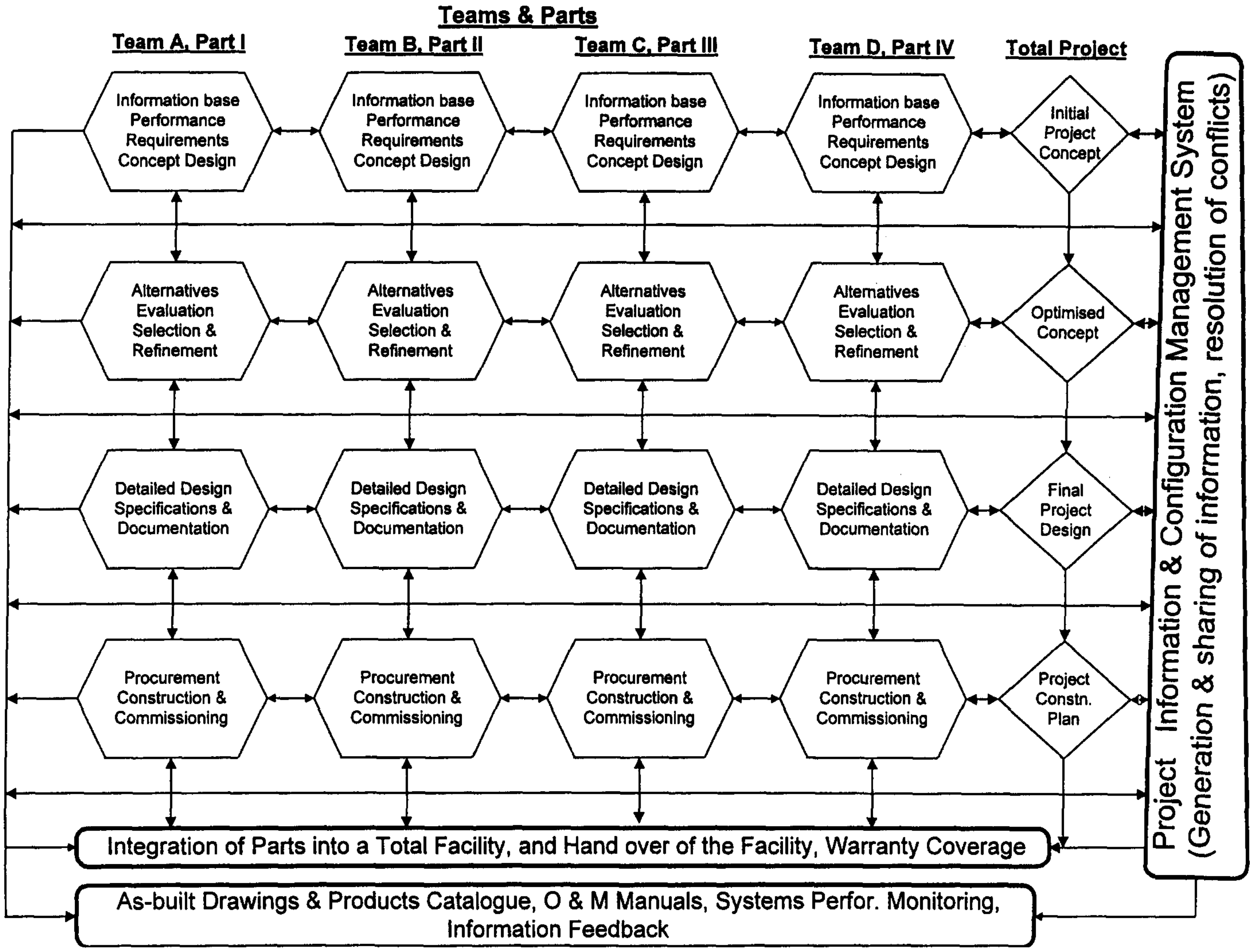

FIG. 2. Schematic Representation of Integrated Communication System in Concurrent Construction

of the facility. There are, however, practical and organizational barriers to overcome before concurrent construction can become a reality.

WILL CONCURRENT CONSTRUCTION WORK?

The construction industry at project level has always been dependent on developing unique solutions for construction of increasingly complex and large-scale projects. Though indirectly the technology is transferred through borrowing and adaptation of the solutions worked out elsewhere, there is no dominant production technology which is universally applicable on all projects, nor is there a need for such, as the industry must respond to a myriad of problems from low cost housing to complex manufacturing or refining facilities, very tall buildings, long span bridges and large off-shore facilities. It is interesting to note that few large capital projects can be found whose construction does not require new techniques or stretching the established techniques to their limits.

The nonrepetitive nature of most construction works, and their dependency on innovative solutions, have significant implications for concurrent construction. For example, one assumption explicit in the concurrent construction concept is that the team formed at the outset to plan a particular part (cluster of activities) or whole of a project has all the solutions ready, or can put the same together quickly through collaboration, and that it is a matter of communication to integrate all these solutions into a single plan for the part under consideration. Even with the advent of smart systems for capturing data on past projects and making these readily accessible to a greater number of professionals in the field, on most significant projects, coming up with all the solutions in a short period of time is impossible. This is because: (1) project scope and objectives vary considerably; (2) project objectives may be based on elements of new technology and development of novel concepts; (3) projects are subject to uncertainties during their life cycle, some of which are not possible to identify in advance or internalize; and (4) site and locality factors often impose fresh challenges.

Turner (1993) states: "Concurrency is sometimes employed quite deliberately to get a project completed under exceptionally urgent conditions, but it often brings major problems in redesign and reworking." The fact is that no single organization has all the technology needed, and on most projects, cycles of planning-evaluation-replanning-appraisal are undertaken to finally arrive at an optimal and practicable solution.

Witness the evolution of offshore oil and gas drilling and production platforms, and the increasingly deeper waters and more hostile environments that have to be conquered; many of these require considerable design, construction and production development, and evolution to make projects viable and sound. Myklebust and Haugan (1996) give an account of a major offshore oil project in Norway, called the Njord Project, in which the contractor developed a new concept for an offshore platform, under the name P45, in response to the need for cost savings, development of more marginal fields, and other pressure factors.

Thus, construction and operation concepts must respond to changing client requirements and cost drivers, such as market pressures, improved quality requirements, newer technologies, and so on. Concurrency may not necessarily work to reduce direct costs on projects, as, under a strict interpretation of this concept, many project parts must be designed with adequate margins and redundancies so as to cope with the wider variations expected due to poorly defined interdependencies between parts inherent in a concurrent construction approach (Myklebust and Haugan 1996). It is worth noting that these interdependencies are created when the project is divided into separable parts and each part entrusted to a team. Within each part a high degree of integration can be achieved as life cycle activities are simultaneously planned.

For example, consider designing a building foundation concurrently with the superstructure, and not having a good estimate of the load that it will have to carry. In the absence of reliable estimates of loads, it may be necessary to design for the worst case scenario, with its attendant rise in direct costs. To avoid this, the designer must await the resolution of the superstructure design. This means that the foundation design will have to be delayed until the superstructure design is sufficiently advanced, and that means that in most instances, the construction cannot start until the foundation design is completed.

Concurrent construction has merits in deliberately focusing on objective functions for decision making, in bringing the downstream views into the planning and design stage, and in making the communication between the relevant team members direct and effective. This will, no doubt, aid development of optimal designs and improved constructibility. It will also give more attention to client requirements or facility operators' needs. Whether it will reduce the total cost, however, is uncertain, and more evidence is needed to support this assertion. If applied literally, concurrent construction may bring some disadvantages. For example, if we progress on the basis of a single team attending to all life cycle aspects and activities related to a part of a project, decisions taken on this part may turn out to be suboptimal vis-à-vis the whole project.

To be optimal, the systems on a given project must be designed on a holistic basis, not as an assembly of many individual subsystems. A heating, ventilation, and air-conditioning system for a building project must be designed as an integrated system, with components chosen to optimize the performance of the building as a whole, over its life time. Thus, it will pay to approach the conceptual design and optimization of the entire system in a holistic manner. This requirement can be incorporated into the concurrent construction approach. One feasible method is to conduct the planning of the systems and their overall configurations at the project level with all parties represented. The agreed configuration and concept design may then be used as an instrument for integration of the parts delivered by individual teams.

CONCURRENT CONSTRUCTION FRAMEWORK

Concurrent construction is both a framework and a philosophy. It is a new approach to work organization and dynamic management of a project. More specifically, it will aid in the development of a unique work breakdown structure which will be amenable to integrating teams with project parts and eliminating redundant management layers. Successful implementation of this approach may involve a revolution in the industry, as the entrenched approaches to procurement, contracting, on-site work organization, and so on will have to be challenged and remodeled. Even project management focus must change; current obsession with contract administration, resource management, and reporting must disappear; instead, focus must be placed on objective-based project development and continuous value addition.

Concurrent construction must be seen as removed from any other concepts, such as risk analysis and management, value engineering and management, quality management, and constructibility analysis. These techniques can be used by teams with the CC framework to achieve the target values set for objective functions, to overcome constraints, and to plan against uncertainties. Concurrent construction defines the overall framework and working philosophy. The most difficult part in the concurrent construction approach is breaking the contractual and work practice barriers which are typically created by the traditional contractual approaches. The owner has a key role in setting the scene for successful application of concurrent construction. To be effective, the CC approach must embrace the entire project life cycle including the business framework under which materials and services are procured for the project. The writer recommends the following approach:

1. Use incentive-based contracting methods, in which contractors and designers for the project will become project partners and their rewards or risks will be decided on the basis of their input and project value achieved. Rewards should be paid not only for actual time and cost values achieved, but also in relation to the additional objective functions of TLCC, cost/worth ratio, IRR, and increased profitability. In this method it is possible to secure true partnership between the parties, as the parties will be motivated to focus their energies on actions which maximize project objectives. Under the traditional contracting approaches, the contractor may find it hard to reconcile the need to minimize exposure to risks and contractual liabilities with the need to work freely under a combined team structure (Jaafari 1996a).
2. Develop a proactive management philosophy. In the context of the CC approach, proactivity has a specific meaning, i.e., a project management philosophy is said to be proactive if it is based on achieving or surpassing clearly specified values for the objective functions. For example, specific target values for capital cost, operating cost, life cycle cost, cost/worth ratio, internal rate of return, or present value may be selected for each system or for the whole project, as deemed appropriate. An implementation framework must be designed to measure the effectiveness of plans and decisions throughout the project life cycle by evaluating their impacts on the selected objective functions. As an illustration, a proactive project management approach may be designed to continuously minimize cost/worth ratios for constituent systems on a public sector project while maximizing the potential benefits from the project as a whole.
3. Use a continuous objective-focused approach for major parts and the project as a whole. This system should be based on driving the project forward in a manner which not only maximizes objective-based decision making at the time of project conceptualization, but also makes contribution to project objectives a continuous process, right up to the operation time and beyond (leading to asset management). Such an approach embodies maximum flexibility in terms of innovation in the underlying concept, timing, resources, and other factors. The project team will typically go through a learning process parallel with the evolution of the project concept. This is necessary as the ambiguities, uncertainties, and complexities in project definition cannot generally be resolved in a short period of time. The advantage of the proactive approach is that it provides the team with a systematic basis

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for the resolution of ambiguities, complexities, and uncertainties, by specifying the objective functions whose values are continuously estimated and assessed.

4. Employ an integrated information management system. Fundamental to the success of the above approach is an integrated or unified project management information system to support the teams in an interactive manner and to provide feedback on the selected objective functions vis-à-vis decisions or changes made to the project design, specifications, construction process, quality, safety, etc., for each part and for the project as a whole. The integration of the work of teams into the eventual facility is, of course, another vital function that the project management information system must support (Jaafari and Manivong, in press, 1997).
5. Use a dynamic scheduling and real-time reporting system to facilitate the management of changes, which will result if maximum flexibility is maintained and changes are made to add value to the project as a whole throughout its life cycle. Given concurrency of the work of the teams, a dynamic scheduling approach is also necessary to aid continuous coordination and integration of the work of the teams (Jaafari 1996b).
6. Use knowledge base systems to aid in the transfer of information from past projects or other sources into the project and its decision making processes, where possible. Use the neural network technology to train the computer to record project-specific patterns and information, and to aid in the management of the soft functions on the project through case-based analysis.

For the implementation of this approach, an initial project model must be established as early as possible in the life of the project. This model, together with the agreed configuration, would be the basis for driving the project forward using the aforementioned objective functions. The clustering of activities, formation and allocation of individual teams to clusters, and concurrent coordination and integration of the work of these teams would be managed using the initial model as a common basis for communication.

INFLUENCE OF UNCERTAINTIES

In the preceding section, reference was made to the fact that even when multidiscipline teams come together to concurrently consider all the relevant information and requirements, they cannot be expected to have all the solutions ready, due to the presence of complexities, ambiguities, and uncertainties and the influence of the stakeholders. Nearly all significant projects are subject to uncertainties and constraints during their life. Sometimes the risks and uncertainties that cannot be identified at the time of initial planning will surface during implementation. Wynne (1992) recognizes the impossibility of knowing all in advance by referring to a "risk" as a situation where the probability of occurrence is known; "uncertainty" as a situation where the probability of occurrence is not known but the main parameters may be known; "ignorance" as a situation where one does not know what one does not know; and "indeterminacy" as a situation where the impact is due to causal chains or weak or open links. Laufer et al. (1996) report that on a sample of 93 capital projects, up to 80% were found to have significant uncertainty on the definition of the facility, right up to the start of the construction.

Thus, it is not possible to resolve uncertainties quickly by making optimistic assumptions and "bulldozing" one's way forward. Doing so may run the risk of temporarily hiding future problems and closing the project's options too quickly and prematurely, increasing the costs, extending the completion date, lowering the quality and performance of the facility, compromising safety, and other failures. This is why it takes a relatively long time to settle the uncertainties on projects. The two widely-asked questions on projects are: (1) What will be the eventual shape and function of the end facility?; and (2) What will be the optimum process for development of the facility?

The first question is normally more critical, as projects do not exist in isolation or in a static world; they are subject to many influences, such as shifting markets, changing business goals, changing technology, appearance of new information, and so on. This means that generally nobody knows the right answer at the beginning, and that several planning iterations and appraisal are needed to locate a perceived optimal solution. More important, however, is the fact that nobody can anticipate what lies ahead, so a cut-and-dry plan may not be flexible enough to cope with the vagaries to which projects are frequently subjected in the post-planning stage. In fact, the teams will go through a learning process. The initial decisions and preliminary concepts are evaluated in terms of the objective functions and in the light of the problems or uncertainties faced. This will improve the team's understanding of the nature of the problems and effectiveness of proposed solutions. Project plan and designs are modified accordingly and the process is repeated until the team is satisfied with the adequacy of the solution. On most projects, this process does not stop at the planning stage, due to continued changes in external environment, and other factors already described.

Can concurrent construction deal with uncertainties effectively? There are essentially two powerful strategies to manage uncertainties over the project life cycle: (1) Maintenance of maximum flexibility in the implementation system so that all options are kept open as late as possible; and (2) real-time evaluation of the objective functions on a continuous basis. Implementation of these strategies requires a system which gives instantaneous and simultaneous feedback on a host of project management functions of both a soft and hard nature (Jaafari and Manivong, in press, 1997). The word "simultaneous" is meant to communicate the need for assessment of the impact that changes may have on the project and on the various objective functions or project requirements. Such a system must be designed to be holistic and "smart" (Jaafari and Manivong, in press, 1997).

CONCURRENT CONSTRUCTION IMPLEMENTATION

As stated, implementing concurrent construction effectively on capital projects requires dismantling many barriers. This will not be easy under the phased contracting system, as the interest and orientation of contractors, consultants, subcontractors and manufacturers are not necessarily always aligned on projects. Under the traditional modes of the delivery the project manager's power to bring all parties together and integrate the same has always been limited, as the expert power is generally dispersed among the project participants (Newcombe 1996).

There are two reasons to believe that implementing concurrent construction may not be as difficult as it appears, if the writer's recommended approach is followed. First, the use of rewards and penalties linked to the target values for selected objective functions will fundamentally resolve the perennial problem of contractual conflict on projects. Experience on past projects has shown that such contractual arrangements have the tendency to transform the relationship among the parties to a contract on a project (Jaafari 1996a; Haugstad 1996; Hetland 1996). Second, the use of a proactive project management approach will fundamentally transform the role of project manager (PM). Under a traditional mode of delivery a different PM is appointed for each phase of the project. Vital information can be lost, and there is no coherence in decision mak-

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ing processes. Moreover, the role of the PM is often that of a coordinator of the inputs provided by other team members. Some project managers even see their role as that of manager of the human resources on projects and administrator of the provisions of the contract.

Under the concurrent construction approach there is one project phase and there will be one PM for the entire project life cycle. Also the PM's role will be transformed, as he or she will preside over the project's objective functions and will drive the entire project activities or organization in a manner which maximizes contribution to the objective functions. The PM will have to deliver the project objectives, i.e., in terms of target values set for objective functions (capital and operating costs, time, quality or performance, TLCC, cost/worth ratio, and IRR or profitability index). Thus, the PM will be involved in the making of decisions which shape the project concept. Apart from active participation in project conceptualization he will exercise a key role in evaluating the impacts of any decision, change, or replanning proposed by the project teams, accepting those which will enhance the objective functions or are necessary for improved operational and safety requirements. The operation of such a project management system requires not only appointment of a PM who is technically and technologically knowledgeable, but also provision of a smart project management system to aid in integrated management of the project teams.

PROJECT MANAGEMENT SYSTEM

How can the project management system function within a concurrent construction framework? The traditional project management systems are ill-suited to concurrent construction for the following reasons:

- Each phase of the project is managed separately
- Information generated and used in each phase is often held by separate organizations and not shared by all the project participants
- No direct link is maintained between decisions made in each phase and the objective functions of the project
- Even within each phase, numerous stand-alone systems and software pieces are used to control the project
- The emphasis is normally on "control" rather than on proactive management of the project or continuous value addition

The concurrent construction approach needs a unified, real-time information management system to hold all key information relevant to the development and management of the project. An integrated information structure must be set up as the core of this system and all project management functions linked to it. Fig. 3 shows how this concept works. The execution of a given project management function will command the system to access all the information relevant to the function under consideration, assemble this information in accordance with the hierarchical model embodied in the processing module for the function, analyze or evaluate the information, and produce reports. Each time a new item of information is entered or an existing piece of information is changed, it would be possible to re-evaluate the status of the project by executing all project management functions on an integrated and real-time basis. Because all information items are held in a unified system, duplicate information entries will be avoided.

The addition of a knowledge-base module and neural network technology to the system will enable deployment of "reflective practice" or dynamic modeling of the relevant information for evaluation of soft functions, such as re-evaluation of the safety or operability of the facility or compliance with the relevant statutory requirements against changes in the project design or specifications.

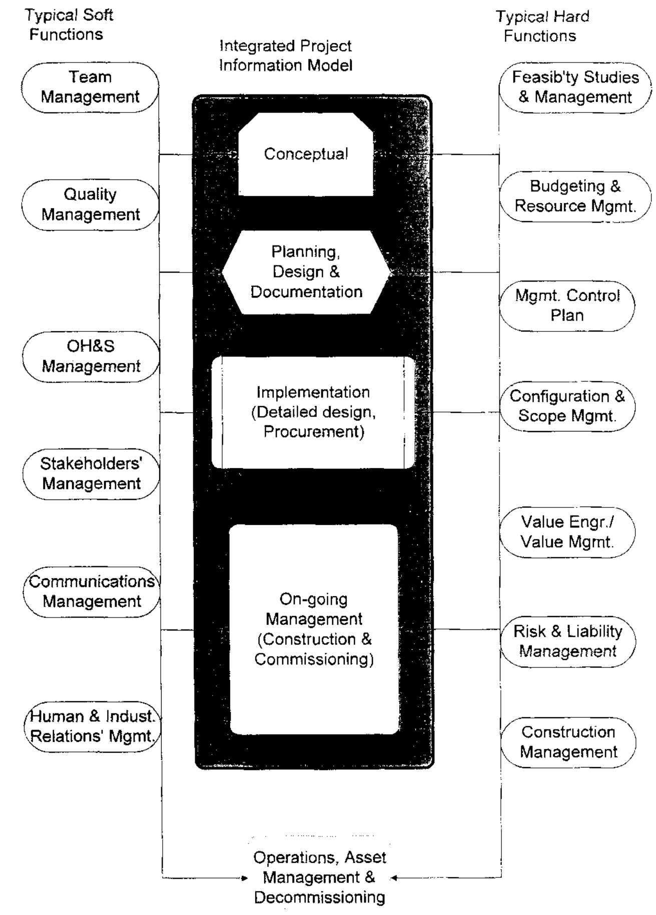

FIG. 3. Schematic Representation of Integrated Project Management System

SPECIFIC PROJECT MODEL

For concurrent construction to be successful, one needs to set up, configure, and rapidly develop a commonly-agreed-upon project model for information management, integration of the work of teams, and real-time execution of the various project management functions. The body of knowledge in the field of modeling projects is growing rapidly. The emerging trend points to the "product" model of a project as an appropriate basis for intergration of the activities of the entire teams, as well as proactive management of project (Dharwadkar and Cleveland 1996; Jaafari and Manivong, in press, 1997; Ito 1994; Sriram et al. 1989; Eastman et al. 1989). A product model does not necessarily comprise only the physical products which make up the project, but also other deliverables, such as design packages. Fig. 4 shows schematically the modeling of a part of the substructure in a building project, i.e., the structural foundation. As can be seen, the products have to be related to the parts with which they interact. Using object-based programming it will be possible to declare a hierarchy of products, with the necessary attributes and linkages (Dharwadkar and Cleveland 1996).

Some authors have advocated parallel modeling of the processes which will be deployed for delivering the products of the project (Ito 1994). The process modeling is meant to simplify the work of the planners or teams who are charged with the planning and delivery of the clusters of activities. This, however, has many drawbacks; it may reduce flexibility of the teams to decide on the processes they want to utilize to deliver their parts of the project. Also, it may deprive the parties to

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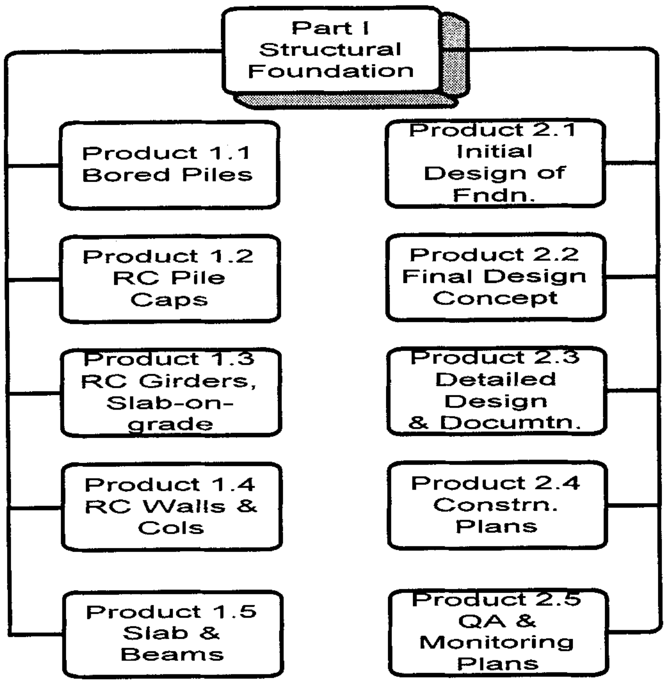

FIG. 4. Schematic Representation of Modeling for Project Part

the contract from rationalizing their resources on the project as a whole. For example, a contractor with responsibility for a line of products within a project may well define the construction process and equipment relative to the entire scope of his contract, thereby optimizing the use of his resources.

The design professionals, too, need to take a holistic view of the project in order to optimize the design of the various systems, such as the structural, mechanical, and electrical systems. At the design level each discipline will thus prefer to define its own process, assemble discipline-specific data, and employ specialized computer software. Thus, the process model within the integrated project management system should only be a suggested broad model based on interdependencies among products and mediated by teams or disciplines that own the execution processes in the field.

Some authors have reported research and development work on computer-mediated collaborative design and construction planning systems, in which the various designers share the same design work space and develop their designs in real time, using a library of stored design elements and other information available. Conflicts are resolved as they arise (Brucker and Stumpf 1996; McGraw et al. 1996; Ito 1994). These approaches are based on the so-called agent collaboration environment (ACE). The agents are expert systems which are rule-based and intended for acquisition, processing, and presentation of information within their domain, as well as instantaneous interaction with one another. In a sense the agents act as information gatekeepers for each discipline, reconciling information received from other agents (i.e., other disciplines), filtering the essential features, and trying to integrate the total for discipline-specific assessment. This process is extraordinarily complex and computer dependent. There are no reports of successful field applications of these techniques as yet. One of the difficulties concerns reconciliation between designs generated by different designers at the time of design synthesis, and the overall effectiveness of the eventual design vis-à-vis objective functions. For example, the structural analysis of a building may use a structural model of the project, which will be totally different from the thermal and energy model developed for the same project.

It seems, therefore, preferable to develop a project-specific model, and use this solely as the basis of communication and integration of the work put in by the relevant disciplines or teams (Jaafari and Manivong, in press, 1997). The following procedures can be used to come up with the product model of the project:

1. Define the level of project breakdown into products. Following the concurrent construction approach, the project is divided into separable parts; each part has constituent systems and products plus associated deliverables, as shown in Figs. 1 and 4. Products are the basis for integration and intra- and interteam communication. So adoption of a fine level of breakdown is not recommended, as it will result in sharp increases in interfaces to be managed, militating against the desired efficiency in configuration management of the project; it will also lead to information overload. As a general guide, the level of division may be related to the acceptance scheme under which teams are supposed to deliver their respective products and deliverables over time.
2. The relationship between products and their associated deliverables may be constructed using the technological dependencies as the basis. To reserve maximum flexibility, the processes required to manufacture or construct the products are to be left open initially (or specified in indicative terms), as the products themselves will be subject to modification, substitution, or even elimination, over the project life cycle. Simulation, animation, and visualization techniques may be used by teams to optimize the construction process further in broad terms. The information on the pertinent products and processes can be fed back to the project manager by the teams and stored within the project information base at a global level, to the extent that it will assist the overall management of the project.
3. The model, strategy, and plans developed can serve as the basis of detailed field planning for construction and commissioning purposes. Forward (approximately six weeks in advance) and detailed (approximately one week in advance) planning, as well as tracking and control, must reside within the teams' jurisdiction to allow flexibility to cope with uncertainties, production variation, and other fluctuations typically occurring on construction projects. This approach will allow maximum flexibility in resource management, as well as maximum opportunity to improve on construction plans and processes after the initial planning stage.

CONTRACTUAL FRAMEWORK

As already pointed out, the traditional contracting approaches for the procurement of design and construction services are not suited to concurrent construction. This is because the traditional contracting methods do not generally lend themselves to teamwork, particularly across disciplines and among contractors, suppliers, and others. In a sense each party to the project tends to manage its own scope in a way that minimizes its own exposure to risks and maximizes its gain. This may lead to the divergence of objectives of the parties from project objectives. This is the reason for the recent trend to more flexible incentive-based contracting systems, examples of which have been reported in the literature (Myklebust and Haugan 1996; Jaafari 1996a).

Terms such as "project alliance" and "long-term partnering" have been used to distinguish these contracting systems from the traditional contracting approaches. The main advantage of an incentive-based contract is in its potential to unite the objectives of the project participants with project objectives and provide conditions for maximum performance by teams. In formulating an incentive-based contract for large and

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complex projects there is often a recognition that uncertainties, complexities, and ambiguities cannot be resolved completely prior to tendering for construction. To pretend that the impacts of such uncertainties, complexities, and ambiguities can be estimated reliably and included in the contract by contractors during the short tendering time, is foolhardiness. A more prudent solution may lie in uncoupling the contractor's (and other team members') performance from the uncertainties and risks outside their control. The contract will then be developed to act as an engine to motivate the contractor and other team members to put in their best for the project. In other words, the contract will align the participating organizations' objectives with those of project objectives. [For a more detailed example of innovative contracting see Myklebust and Haugan (1996) and Jaafari (1996a).]

The success of the concurrent construction approach is hostage to the timely employment of all team members, including the contractor, so that composite teams can be formed for each part of the project at an early stage. It is also dependent on the contractor's willingness to work flexibly under an integrated team structure. These requirements show that newer forms of contracting must be pioneered. Design-and-build and construction management type contracts are perhaps better suited to the adoption of concurrent construction than the conventional lump-sum, fixed-price contracting. However, even these need considerable changes to respond to the needs of concurrent construction. For example, in the design-and-build approach, the owner and operator will not be able to influence the shape of the project in a major way except through the initial design concept or setting of target values for the objective functions, such as the TLCC per-unit output. This is fine, but it should be noted that concurrent construction requires the ongoing participation of the owner and user or operator of the facility to continuously resolve expected changes and maximize contribution to project objective functions.

In the case of construction management, the main focus tends to be on the division of the project into packages which can be managed contractually as separate deliverables. These packages are for procurement of design deliverables, procurement of materials and equipment, or for field construction works. The construction manager's task is mainly confined to coordination of the works and management of the interfaces created through the division of the works into multiple contracts. This is not concurrent construction, as there is no integrated team and parts approach. Further, there is a tendency for the contract administration function to consume an extraordinary amount of project management resources. There is no guarantee that the constructed facility will meet the objectives set beforehand. While there is more flexibility (compared to the design-and-build approach) to respond to owner-initiated changes, by and large each contractor or designer sees his role as that of satisfying his contractual requirements. The potential for errors to creep in will increase under this system. This is because the output of the work done by one firm is the basis for the work performed by others. Tracking and allocation of responsibility for errors will be a time-consuming process leading to contractual conflicts, claims, and cross-claims. This is inefficient and will ultimately lead to delays, cost overrun, and disillusioned owners.

Given the need for an integrated team approach, in concurrent construction a very flexible form of contract is used, in which the cost of resources provided by participants are borne by the project using some pre-agreed-upon formulas. The contractor's profit or reward (or penalty) must be linked to the ultimate achievement of the objective functions on the project. This system will encourage teamwork and will motivate project participants to put in their best endeavors for the project, as their future will depend on the successful conclusion of the project and a generally satisfied owner.

FUTURE DIRECTIONS

Research and development in progress at the University of Sydney is centered on developing an integrated facility engineering (IFE) system which will facilitate implementation of the concurrent construction concept. While it is still too early to speculate about the eventual outcome of this effort, the results so far indicate that such a system is feasible and can be a valuable tool in the quest for full implementation of concurrent construction.

CONCLUSIONS

The writer has attempted to explore the origins, meaning, and application of concurrent construction. It has been shown that concurrent construction has the potential to reform the project processes in a fundamental way. An overall framework for the implementation of this concept has been presented. Concurrent construction will provide a collaborative environment for the parties to the project to work in an integrated manner.

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