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COORDINATING SPECIALISTS

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ABSTRACT: Specialty contractors (SCs) are construction's 'job shops'. They must allocate their resources to match the various 'delivery' dates demanded by multiple projects. Managing the production of a specialty contracting firm is, consequently, quite different from managing a project. Further, specialty contractor management depends upon the quality of production management on projects, i.e., their coordination by general contractors. Unfortunately, there is a trend among general contractors to adopt a brokering role and neglect coordination. This paper presents the production and control tasks of both specialty and general contractors through the use of process models, emphasizing the responsibility of SCs for design completion and the mutual interdependence of SCs on design changes and installation accuracy. Lean production principles are recommended and CPM is critiqued as inadequate for SC coordination.

INTRODUCTION

Specialty contractors (SCs) perform construction work that requires skilled labor from one or at most a few specific trades (e.g., electrical, plumbing, HVAC, roofing, iron work, and concrete) and for which they have acquired special-purpose tools and equipment as well as process know-how. Because of this specialization, their work is limited in scope relative to the work required to complete an entire facility, so several SCs will have to pool their efforts in order to bring a project to completion. It is not uncommon for large building projects to involve twenty or more specialty contractors.

Most commonly, specialty contractor involvement in a specific project is established on a contractual basis. A general contractor (GC) may ask for competitive bids from specialty contractors and then, once awarded the new project by the owner, negotiate subcontractor agreements with various SCs as needed to cover the entire project scope of construction work. The general contractor may choose to do some work with its own forces. On occasion, a specialty contractor may lead the construction effort, thereby adopting the role of general contractor. Important to note is that there are no contractual agreements between subcontractors: their joint participation on a single project has been arranged through general contractor-subcontractor agreements. The role of the general contractor then is to orchestrate all subcontractor activity much like it is the role of a conductor to direct instrument players so that they will perform a musical score symphoniously.

Subcontractor activity not only pertains to construction work on site, but, out of necessity, also to work related to design completion (e.g., Sadonio et al. 1998). Indeed, it is seldom the case that contract documents, including design drawings and specifications, are unambiguous and sufficiently detailed to be of direct use to specialty contractors.

Shop-drawing detailing followed by architect-engineer (AE) approval is often expected of specialty contractors, but this process more often than not reveals incompatibilities in the design documents that are presented to them and vagueness in their scope of work. Numerous requests for information (RFIs) get issued in consequence. Claiming that design is 100% complete at the time of contract award is unrealistic. This is expected in design-build work but it also applies when construction is procured through the traditional design-bid-build method. It must therefore be acknowledged that the contractor and subcontractors' involvement in the project begins, not with the start of construction, but with completing the design.

SPECIALTY CONTRACTOR PRODUCTION PLANNING

Specialty Contractor Production Tasks

At first glance, the task a specialty contractor is to perform appears to be straightforward: conduct work on site as spelled out in the contract documents and do so in a timely fashion as set forth in the general contractor's overall project schedule. At least, this is the view presented in the critical-path method (CPM) schedule, created by those managing and overseeing the project, namely the general contractor and owner.

Prior to mobilizing on site, however, the specialty contractor must successfully complete numerous off-site preparation tasks. These are termed production tasks to reflect that they result in the creation of drawings and purchase orders, mobilization of labor, arrival of equipment, and delivery of materials; that is, 'products' necessary to perform construction work on site. First and perhaps most important, however, are the specialty contractor's control tasks that consist of planning,

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scheduling, and controlling its production tasks. As work progresses, control tasks are performed concurrently with production tasks, and replanning and rescheduling will take place as needed.

Typical specialty contractor's off-site production tasks include:

1. Obtain design drawings and contract specifications describing the specialty contractor's scope of work by selecting those of relevance from what has been provided by the architect engineers to the general contractor.
2. Create detailed fabrication and installation drawings. This detailing process is based on input from the architect-engineer's design and results in detailed shop drawings that include fabrication details. This is a value-adding process in which the specialty contractor can reflect its methods design and process know how.
3. Perform materials take-off (MTO), send out requests for quotation (RFQ), and select vendors.
4. Procure off-the-shelf materials or order custom-fabricated components.
5. Expedite delivery of materials.
6. Hire (if need be) and schedule labor.
7. Obtain equipment, tools, temporary structures, etc.

Work then shifts to mobilization and production on site, including the tasks:

8. Execute construction work to produce output (work completed).
9. Close out the project by extending warranties and requesting/receiving final payment.

These specialty contractor production tasks succeed each other more-or-less in sequence, as is illustrated in Figure 1.

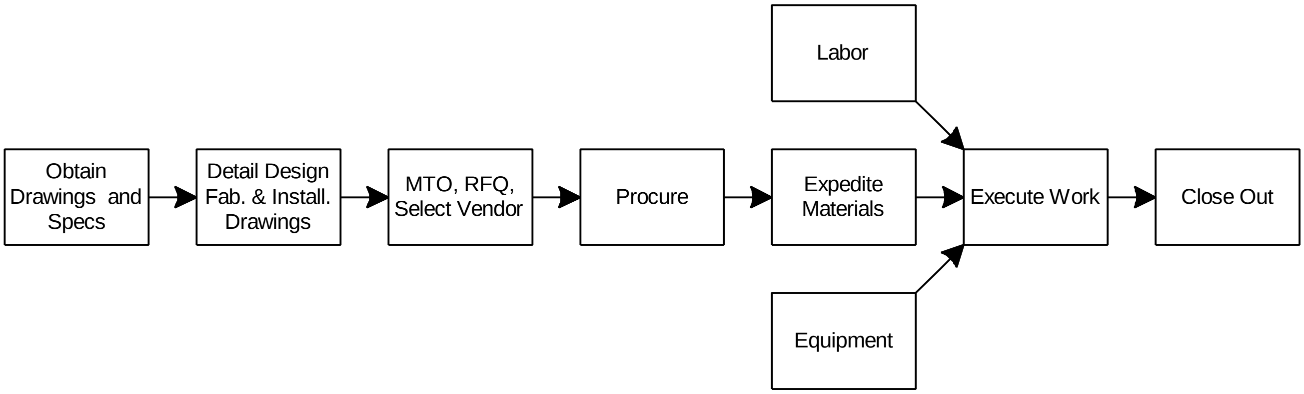

Figure 1: Specialty Contractor Production Tasks

Specialty Contractor Production Plan

The work performed by a specialty contractor on any one project (we refer to it as a 'job') is not only limited in scope; more importantly from a production planning standpoint, it is of a fairly short duration (depending on the trade) relative to the duration of the project as a whole. A specialty contractor, much more so than a general contractor, therefore needs to be involved in a multitude of projects at the same time so that it can tightly sequence its work, make best use of its equipment and tools, and guarantee continuous employment to its workers. The latter is necessary for the specialty contractor to be able to invest in specialized training of its workers and gain from their skilled work over time, while also building up and maintaining company-specific process know-how.

Some jobs will, of course, be larger in scope than others, and no two are ever identical. Nonetheless, many jobs will require the specialty contractor to perform about the same production tasks, possibly requiring different amounts of resources and extending over different lengths of time. Some jobs may start later than others, yet require that they be finished first. The specialty contractor must therefore assign its resources (in-house personnel such as design detailers as well as on-site personnel, construction equipment and tools, but also hauling equipment and office computers, etc.) so that their use is balanced and work gets done according to promised completion dates. This task is called job-shop scheduling.

Job-shop scheduling differs from CPM scheduling in that there is no finite time limit (or project completion date) to all work ahead from which a backward pass can be calculated to determine the critical path. Instead, it is characterized as having an infinite time horizon with an unlimited flow of new jobs coming in, each possibly with its own milestones and due date, but most of them having 'float' so they can be interwoven with other jobs. Job-shop scheduling is driven by throughput, that is, the need to perform various production tasks in sequence in order to finish every single job as soon as possible, while at the same time balancing resource availability, priorities among jobs, and schedule constraints.

Figure 2 illustrates the situation specialty contractors face. Queues (circles with a tail) represent none, one, or several resources waiting to be processed, whereas combination activities (rectangles with a cut-off corner, also called combis) represent production tasks that require those resources as input.

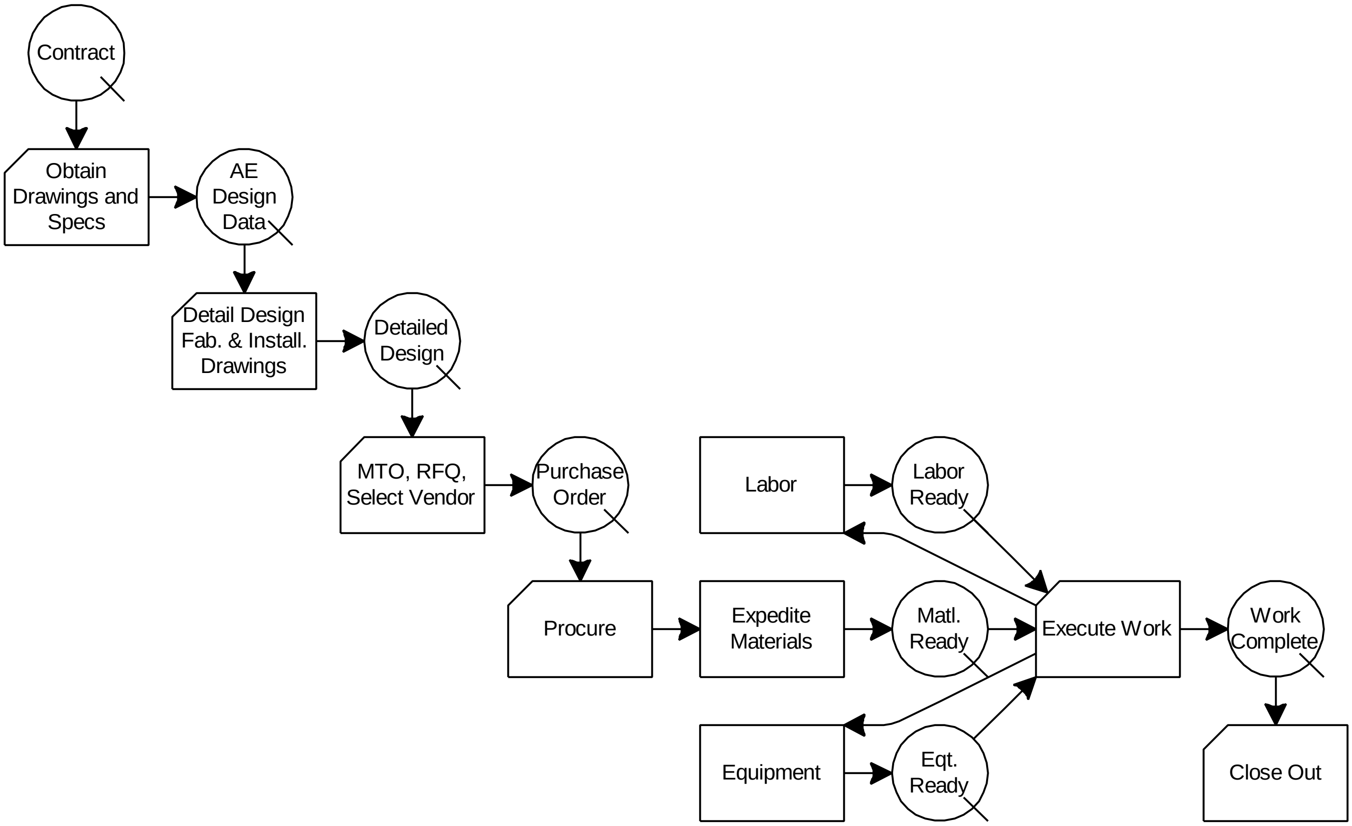

Figure 2: Work Flow Model of Specialty Contractor Production

Prior to starting any one task and committing the appropriate resources to it, a decision must be made (not illustrated) on which resources to select first. This way, the specialty contractor controls who works on what and which work gets done when, in order to meet the general-contractor's CPM schedule on each of its jobs while at the same time balancing its own work load and resource use.

Specialty Contractor Coordination Needs

The sequencing and timing of production tasks 1 through 9 are not under the exclusive control of the specialty contractor. Several tasks require work to be done by others and cannot start and/or finish unless others have finished theirs. Examples of such third-party tasks are:

10. Clarify contract documents and specialty contractor scope of work. This is handled through requests for information (RFIs) sent by the SC to the general contractor who may forward them to the architect/engineers (AEs) for resolution.
11. Obtain design updates and drawing revisions, review them for possible impact on scope, methods, or cost, and reflect those impacts in the appropriate agreements and documents; e.g., contract, drawings, budgets, schedule.
12. Review change orders and RFIs submitted by others, looking for possible impacts on the SC.
13. Acquire as-built data for work done by others on which the SC must build (literally!). Unless exact field dimensions are obtained for such work it may be impossible for the subcontractor to complete design details, thereby delaying procurement, fabrication, and field installation. The need for as-built data typically affects only a fraction of a SC's work, but that fraction can be critical in determining its ability to start and complete work on site.
14. Obtain GC and AE approvals for shop drawings. The wait for approvals delays procurement unless the specialty contractor is willing to bear the associated

risk of having to pay for materials twice. This risk may be especially onerous when fabrication is involved, since custom fabrications can seldom be used elsewhere.

15. Schedule use of equipment shared with others on site (e.g., hoisting equipment).
16. Stake out space to off-load, stage, and transport materials, and to allow workers to access their work area and work without obstructions (noise, dust, debris, etc.)
17. Have other specialty contractors complete prerequisite work, that is, construction that must have been completed before the specialty contractor can do its work.

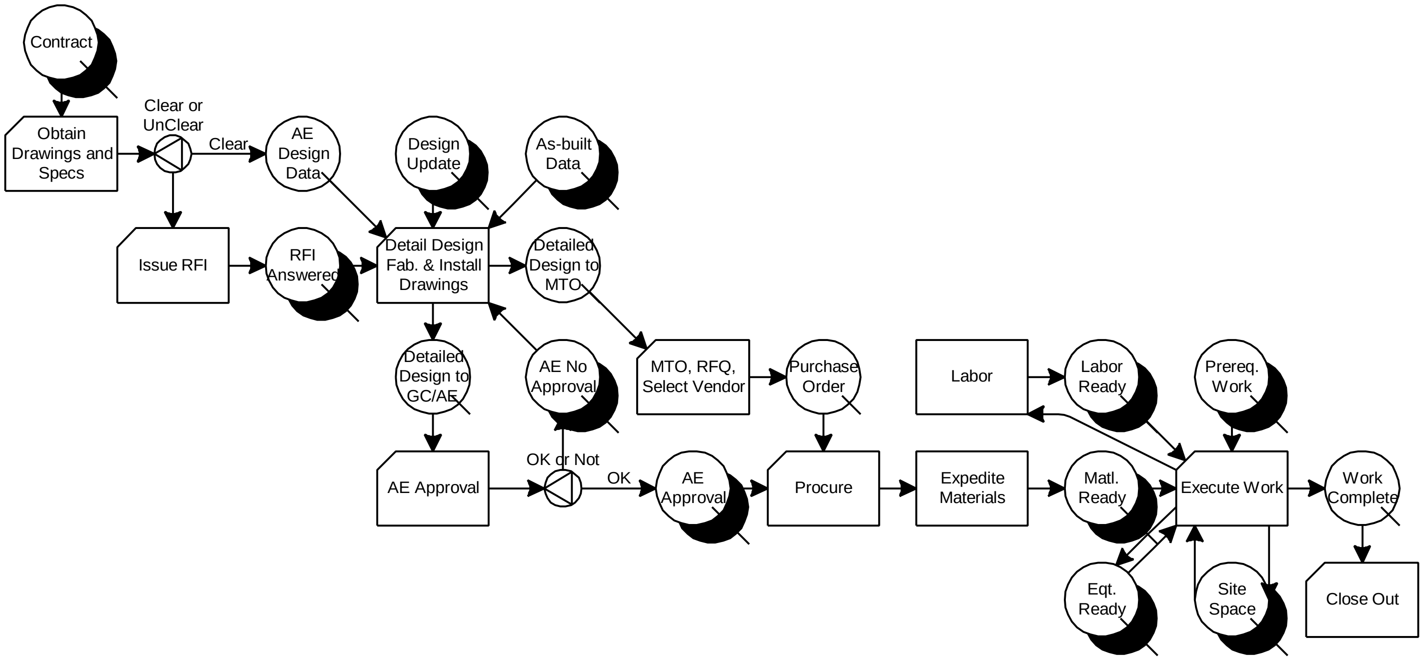

Figure 3: Work-flow Model of Specialty Contractor Production Subject to Third-party Constraints

Figure 3 shows where such third-party tasks may have an impact on the specialty contractor's production plan: resource constraints (queues) have been added. This means that when the resource is not available, the production task itself will be delayed in part or in its entirety. Note that material ready and labor ready may also be a third-party constraint though they are not labeled as such in this figure.

This flow model depicted in Figure 3 highlights that the specialty contractor will not be able to proceed with production as planned when (1) design changes take place (e.g., changes requested by the owner), (2) delays arise in obtaining clarification or approval, and in the completion of work done by others; and (3) on-site space or shared equipment are not readily available. The specialty contractor must be well aware of these uncertainties and manage its job shop accordingly. Lean production techniques help in this regard. For instance, the specialty contractor can shield (Ballard and Howell 1998) the detail design activity from uncertainty (will the design fit or match up with work already in place when executed on site?) related to inaccurate or missing as-built data. Though pressure to do otherwise may be great, design can be delayed until prerequisite work is completed, so that field measurements can be made and relayed back to the office. Determining which parts of the design can proceed without the information vs. which parts cannot is crucial to avoiding rework.

COMBINED PRODUCTION PLANS FOR MULTIPLE SPECIALTY CONTRACTORS

Figure 3 illustrates a key characteristic of work done by specialty contractors: a substantial number of off-site, preparatory activities must be completed before work on site can be executed. Accordingly, a specialty contractor needs a fair amount of lead time prior to mobilizing on site. This lead time is governed by the time it takes for the contractor to perform those preparatory activities, subject to its resource load and capacity constraints. Unfortunately, this lead time is often violated due to lack of design data and management pressure to start work on site. Design is forced to proceed with a high likelihood that redesign will be necessary. Labor and equipment are ready for work but there is no material to install, no prerequisite work in place, or no unobstructed access and work space available.

The coordination of specialty contractors is a most challenging task because many such contractors will be performing work concurrently and competing for site resources, e.g., space for storing materials and access to hoisting equipment. Their production plans are interwoven with one another. Figure 4 illustrates, for example, how a heating-ventilation-air conditioning (HVAC) and a sprinkler-system specialty contractor might compete for equipment and site space resources. Bulky materials usually are installed first, so the HVAC contractor is likely to be ahead of the sprinkler contractor (David Riley quoted a site manager saying they form a 'parade of trades'). However, both will need access to the same areas in a building and therefore they are likely to interfere with one another. Figure 4 also shows that RFI clarifications for one (shown at the top) may result in design details that affect the other (shown at the bottom), and that as-built design data and progress on completing prerequisite work must be relayed. Although this figure shows only two interwoven production plans, in practice there could be many knitted together on any project.

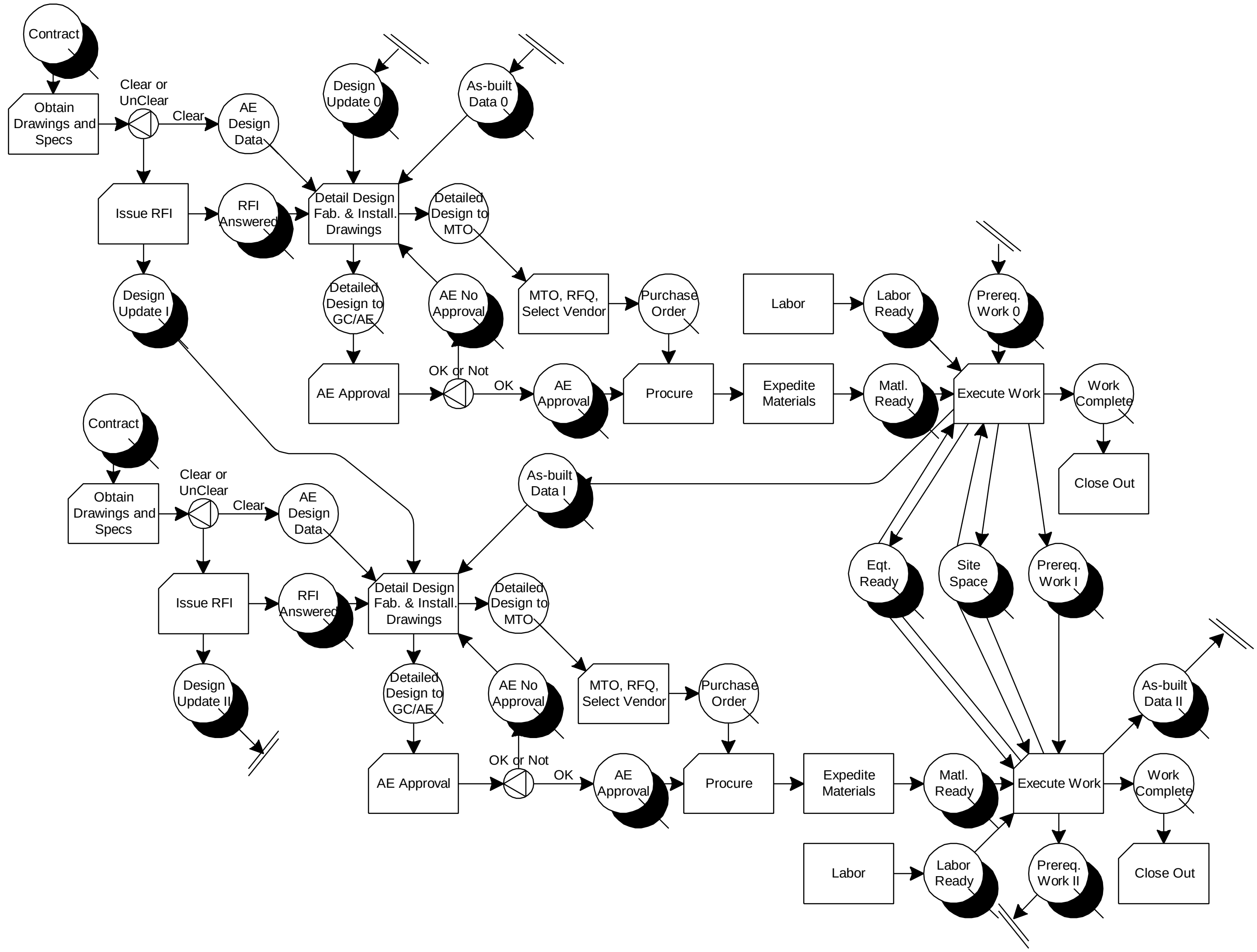

Figure 4: Interwoven Production Plans of Multiple Specialty Contractors

Interesting to note here is that project management's CPM schedule is virtually useless in showing the real interactions that take place among specialty contractors at the site and off site. CPM cannot be used to coordinate the work of subcontractors simply because it has insufficient detail to reflect the relevant process characteristics. It could be argued that the CPM schedule can be made as detailed as one wishes and, consequently, that the fault does not lie with the tool but with the tool user. The only way CPM can try to accommodate greater complexity is with greater detail, and the usability limits of greater detailing are soon met. Perhaps a stronger criticism is CPM's limited ability to model resource interdependencies and flow. Accordingly, it would be awkward for a specialty contractor to demonstrate using CPM how the AE's delay in resolving an RFI, for instance, or a change in design, impeded its progress on site. A CPM so detailed would be very difficult to update and prone to error.

GENERAL CONTRACTOR TASKS VIS-À-VIS SUBCONTRACTORS

On projects where several parties need to orchestrate their work, those parties will be served best if one of them takes the leadership role to coordinate their assembly processes. This role is best fulfilled by one who serves the interests of the project as a whole. Logically, this typically will be the general contractor who signed the contract with the owner for completing the project on time and within budget.

Independently of who takes on this role, the specialty contractor coordinator must perform the following tasks:

1. Relay information about design updates to the appropriate specialty contractors.
2. Help resolve design and specifications ambiguities on site if at all possible, or else, promptly handle RFIs to and from the AEs. Clarify issues of scope gap and scope overlap as early as possible in the project.
3. Keep track of all design updates, including those resulting from RFIs, for instance by creating a 3D CAD model of the project and keeping it current as the design evolves and construction progresses. Inform all specialists affected by the update and not just the one who submitted the RFI.
4. Provide means for as-built data and progress on prerequisite work to be communicated in a timely fashion to those whose work is affected by it.
5. Work with specialists to develop their production plans at a meaningful level of detail and relay those plans to others involved in the project. Organize regular planning meetings.
6. Schedule the final assembly process in which the specialty subcontractors play the role of 'workstations'. Detail the process interdependencies in the handoff of work-in-progress from one station to the next as each task begins to come into view, perhaps 3-4 weeks before scheduled execution. Continuously collect status information from each subcontractor regarding their readiness to perform future tasks, facilitate the resulting negotiations, and adjust the assembly schedule accordingly.
7. Provide and schedule the use of shared resources as needs change over time (such as hoisting equipment; space for access, materials storage and handling, and execution of construction work; containers for trash and debris, etc.) so specialty contractors can reliably plan their flow of materials and sequence of work.
8. Reward contractors with timely payment.

Unfortunately, not all GCs agree to adopt this coordination role. In recent years, it has become more common for those managing projects to adopt a hands-off approach vis-à-vis SC coordination. They agree to be contract brokers but nothing more than that, thereby trying to maximize company profits by keeping project overhead costs at a minimum and leaving specialty contractors to fend for themselves. It should come at no surprise that this strategy often backfires. On a cutthroat project, subcontractor relations are more likely to turn sour than they would on a project where the general contractor tries to facilitate the work done by all involved. Brokered projects may exhibit an excessive number of RFIs, submitted to raise the likelihood for change orders and thus extra pay to contractors, and also paper work building up to support litigation upon project completion.

In contrast, we advocate the use of detailed production planning to benefit not only all project participants but also the project in its entirety. We claim that projects of higher quality can be built faster and for less money, while at the same time yielding all participants higher profit margins, because production planning—a technique that supports the lean production philosophy—helps trim wasteful delays and rework from production cycles.

RELATED WORK

Bennett and Ferry (1990) present an excellent review of the emerging role specialist contractors play in the U.K. building industry. They elaborate on the implications this has on project organizations, contracts, design, site coordination and meetings, information technology, and quality. Labor shortage and the need for training future specialists are high on their list of concerns. Despite this recognition, little research (Tracey 1991, Hinze and Tracey 1994, 1995, Borg 1995) has been conducted to date on specialty and subcontracting although construction projects increasingly rely on the work of specialists for their successful completion. Many interesting research issues therefore remain to be investigated.

We classify related work in two categories: (1) contract management and (2) coordination achieved by means of properly structuring the construction organization and then managing production. In reviewing the literature, we touch upon a wide range of subjects but note that over the last thirty years, contract management has gained in prominence and perceived importance. Unfortunately, this has come at the detriment of production management. We suggest that contract and coordination management be balanced more evenly. Because production management has been overlooked for so long, we focus our attention in this area.

Contract Management

The management of subcontracts is the subject of several specialized texts (e.g., Curry et al. 1991, Uher 1991, Hinze 1993) that pay attention to subcontractor prequalification and selection, and subcontract conditions such as allocation of risk, handling of change orders and delays, bonding, retention, and terms of payment. They also point out the necessity for coordinating work though fail to provide specific directives.

Owners may structure contracts so as to promote subcontractor involvement. On large projects they may require that a certain percentage of the work be subcontracted out in order to give smaller companies an opportunity to participate. In the extreme, owners may not want the contractor (or design/build firm—we know of a few such instances!) to perform any work at all, in an effort to avoid conflict of interest and to obtain the best prices on competitively bid subcontracts. Regrettably, in such circumstances, when company profits are reduced by costs of controlling the job, the broker-contractor has little incentive to plan, organize, supervise, and coordinate the work (Hinze 1993 p. 13). Subcontractors see proper coordination as being essential to their ability to perform (e.g., Birrell 1978a, 1978b, 1985). They mark up their bids accordingly when management staffing is unknown at the time of bid submittal or when they anticipate that they will inadequately fulfil their coordination role (Birrell 1985, Uher 1991).

Contracts must, of course, be agreed upon at the onset of a project, adhered to during project execution, and revisited after project completion in case disputes have arisen. However, contract management has become a significant burden to the contractor, taking away from time spent managing work. Royer (1986) points out how the critical-path method, originally developed as a means to support planning, has become an administrative and legal instrument, thereby adding to the general contractors' work and detracting from their main responsibility, namely managing construction workers and subcontractors. Some owners today demand that contractors submit pre-project schedules for multi-year projects where each activity has a maximum duration of 15 days and only 10% of all activities have a float of less than 10 days. Clearly, such schedules are doomed to fail from the start and contractors must count on spending a tremendous amount of time negotiating schedule changes with the owner's representative.

Based on a study of Australian subcontracting practices, Uher (1991) concludes that general contractors include many harsh conditions when issuing subcontracts, even though they may have no conscious intent to apply them. 267 subcontract packages were examined and each included a liquidated damages clause. 95% of the subcontract packages were delayed for a variety of reasons but only once was a liquidated damages clause used against an offending subcontractor (p. 503). The general contractor's reluctance to impose the clause might have stemmed from the recognition that pursuit of legal remedies could lead to even greater financial losses. Nevertheless, when faced with onerous conditions, subcontractors make allowances in their bids because such conditions add to uncertainty. This practice increases the project cost and also 'the client's risk either through the insolvency of subcontractors, an increase in the level of claims and disputes, or by cost-cutting measures on the part of subcontractors which affect the quality of the works' (p. 496).

U.S. subcontracting practices may not be too dissimilar. For instance, Article 3 in AGC's 'Subcontract for Building Construction' (AGC 1990) prescribes:

> 3.3 SCHEDULE CHANGES. The Subcontractor recognizes that changes will be made in the Schedule of Work and agrees to comply with such changes.
>
> 3.4 PRIORITY OF WORK. The Contractor shall have the right to decide the time, order and priority in which the various portions of the Work shall be performed and all other matters relative to the timely and orderly conduct of the Subcontractor's work. The Subcontractor shall commence its work within ___ days of notice to proceed from the Contractor and if such work is interrupted for any reason the Subcontractor shall resume such work within two working days from the Contractor's notice to do so.

The document proceeds by stating how changes, claims, and delays will be handled. An unstated assumption underlying these contract clauses appears to be that subcontractors will have no capacity limitations nor other capacity demands (projects going on concurrently) so they will be able to respond immediately to any project changes. That this would be the case or is possible for the subcontractor to achieve at no extra cost is unrealistic. Yet, compensation mechanisms are not clearly spelled out, if they exist at all.

In contrast, the New Engineering and Construction Contract (NECC) used in the Great Britain (Telford 1995) is explicit on this issue. Section 31 requires subcontractors to submit schedules that include methods, equipment, and resources for each operation and the dates when the subcontractor will need information, materials, space, and prerequisite work completed by others. The contractor must respond within two weeks after receiving a proposed schedule. To reject, the contractor must show that the subcontractor's plan is either deficient or impractical. Once accepted by the contractor, any change to the subcontractor's schedule is a compensation event. For example, as seems imminently reasonable, the contractor may instruct a subcontractor to stop or not start work. That is an element in all standard subcontract forms. However, Section 60 in the NECC explicitly says that such changes are compensable.

In summarizing the literature, we have chosen not to elaborate excessively on contracting issues related to working with construction specialists, because contracting is but a means to the ultimate objective on any construction project, which is to get the project built. As an alternative, we wish to promote improved coordination by means of properly structuring the construction organization and then managing production.

Coordination Management

Structuring of Organizations

The Tavistock Institute (1966) presented a socio-technical system framework for the construction process, articulating the nature of uncertainty and interdependence in the building industry thirty years ago. It critiqued industry organization as being ill-shaped by roles that 'have become entrenched and protected within institutes, federations, and associations designed to protect the interests of those carrying them' (p. 43). It also placed high expectations on the use of better management tools to achieve much wider coordination of control. Since then, unfortunately, problems have only increased due to greater pressure for timely project completion, owner demands for continuous cost reduction, and greater project complexity. At the same time, the construction industry apparently has pursued the legal route to hedge its bets, rather than pursuing the alternative, namely digging into process details, identifying and reducing sources of uncertainty, and managing production along the lines of what was done in manufacturing (e.g., Schmenner 1993).

Construction management became a well-established specialist skill in the 1970s (Subcommittee 1979, Birrell 1978a, Barrie 1979), adding a layer to the organizational structure of construction projects. Yet discussion remained as to whom is best positioned to perform the subcontractor coordination task and provide general conditions facilities (e.g., Birdsall 1980, Subcommittee 1980). The widespread dislike of management contracting was pointedly characterized by a specialist contractor who stated 'it gives management contractors authority without responsibility and specialists responsibility without authority' (Bennett and Ferry 1990 p. 267).

Birrell (1981) describes that it is an informal but organized group that manages construction. The organizational structure portrayed in contract documents bears little relation to the ad-hoc organization that forms out of necessity to make the project work. Clearly, the contracting approach has not kept up with the changing nature of construction organizations as they adapt to meet new demands, for instance by adopting design-build approaches and recognizing the design role of specialty contractors and manufacturers (Pietroforte 1997).

In an effort to promote good relationships among project participants, partnering has now become widespread in use. However, partnering does not go far enough (Miles and Ballard 1997). It remains too vague as a technique and does not necessarily lead to the establishment of a formal process that will enable project participants to coordinate their work efficiently and effectively.

Tatum (1986) bases his work on that of Thompson (1967) and derivative work on contingency theory, as well as Mintzberg's (1979) four parameters for describing organization structure (1) grouping and sizing of organizational elements, (2) means of coordination between units, (3) location of decision making, and (4) requirements for positions. He stresses Galbraith's (1977) suggestion that coordination can be improved by adding personnel but also by investing more heavily in planning, monitoring, and control systems. Tatum recognizes that performance control and action planning are not normally considered part of organization structure in construction (p. 261) but unfortunately provides no specifics as to how current practices should be enhanced to better support coordination. Our work, by contrast, shows how specific lean construction techniques (see later in this paper), several of which pertain to more thorough planning and measurement of plan failure, improve coordination and the likelihood of project success.

As the basis for organizational design, i.e., for choosing whether or not to employ specialty contractors among other services providers, Winch (1989 p. 337) poses the question: "Why do construction firms choose to contract for construction services, rather than employ the capacity to provide those services themselves?" He adopts the transaction cost view, first articulated by Williamson (1975, 1979), though he recognizes that while data is widely available on production costs, little is known about transaction costs. Because construction firms face complexity within each project (classified as (1) task uncertainty, (2) natural uncertainty, (3) organizational uncertainty, and (4) contracting uncertainty) and deal with 'small numbers' situations, hierarchical relationships between designer/general contractor and contractor/subcontractor specialist appear to be favored over market structures.

Winch does not consider the possibility that a decision to buy rather than make is influenced by recognition that production management capability may be low and, consequently, production risk high. Contracting in the traditional fixed price mode shifts the production risk from the general contractor to the subcontractor. If it were possible to improve production management capabilities and thus reduce risk, the relative merits of buy over make could shift in favor of the latter. Pietroforte's (1997) suggestion of a federative form of organization, between market and hierarchy, also is an alternative worth exploring. Surely there must be some limit to the efficiency of self-performing work, in which case a federative form of organizing specialists seems the most useful. Cost-plus contracts can be used to construct such federative organizations.

It is also worth noting that a fixed price contract commits the subcontractor to submit to the hierarchy of the project. The hierarchy is likely to fail when the contractual terms themselves must be revised or when demands to comply with contract terms are perceived to be inappropriate. O'Brien's (1995) case study demonstrates the difficulty in finding actions in such circumstances that equally distribute costs and benefits among the participating companies. Consequently, one criterion for organizational and commercial structuring is that they facilitate the selection of actions that benefit the global project. As such, they must anticipate problems of the type ‘Who pays and who gains?’.

Much organizational design work is based on abstract organization charts that show functional roles and responsibility links, possibly augmented by coordination links. Jin and Levitt (1996) made organizational design more concrete by developing a computational model for a virtual design team (VDT) that allows for experimentation. Similarly, Lin and Hui (1997) developed a model to describe and compare lean and mass organizations. Both research teams assess the quality of their organizations based on buffer sizes and response times, yet neither one provides systematic guidance beyond "(re)assign work" and "reduce the buffer size" on how to improve their organizations. Both adopt an information processing view and omit detail of the actual activities to be accomplished and their resource requirements (besides people). If we say that these frameworks adopt a top-down view of organizational design, our work is complementary in that it provides a bottom-up view. We are studying the interrelatedness and uncertainty of activities, resources (including people), work methods, physical materials, as well as information flow (Fisher and Yin 1992), in order to better structure organizations to successfully perform those activities.

This review of papers on the design of construction organizations is by no means comprehensive. In studying other work, however, we found that few researchers have specifically addressed the issues that arise when independent specialists are included in the temporary project team. Considerably more research needs to be done in this area. We propose that such research adopt a production view at the construction process level, so that construction organizations can be studied in terms of the processes that are being carried out by the firm and the outputs it produces.

Production Management Based on Lean Construction Principles

The contract management and organizational design views disregard work processes. Production management principles must be applied in order to achieve timely, cost-effective, safe, and high quality project completion.

The need for effective production management becomes obvious when one considers existing coordination practices. In another critique of broker contractors, Haltenhoff (1995) points out that ‘using the general contracting system, owners allow the general contractors to qualify, select, and control the trade contractors and then choose the general contractor to manage the project on the contractor’s ability to submit a low bid, rather than on the demonstrated ability to manage the project. Owners and design professionals remain at arm’s length in the selection of trade contractors, and gullibly assume all general contractors are competent managers.’ We agree that contractors should be selected and rewarded for their ability to manage well. We also stress that effective coordination management is likely to lead to increased production, in turn allowing for more competitive pricing when specialty contractors can reduce contingencies in their bid prices and possibly be granted cost-plus or guaranteed-maximum-price contracts.

Griffis and Butler (1988) also argue in favor of cost-plus contracting over competitive bidding. A necessary condition for this to be successful is that a team approach be adopted and supported by means of effective planning and real-time control during project execution. This requires tracking intents and commitments as soon as they are made, not reacting to cost expenditures in an ad-hoc fashion as seems to be common practice.

Halpin (1993 p. 420) stressed the relationship between composition (design) and performance (production/ performance). "In the past, the idea of the ‘how’ has been neglected. It has been assumed that once the design is finished (i.e., the ‘what’), someone will figure out how to build it (i.e., the ‘how’). The general thought has been that experience from previous ‘performances’ will be sufficient to solve the how questions. Unfortunately, we are already encountering projects for which this old way of thinking doesn’t hold up." We too adopt a production view of construction. Our development for a theory of construction at this level is supported by the implementation of lean production principles.

The lean production philosophy, since it emerged in the 1950s, has had a major impact on the Japanese manufacturing industry. Its benefits gradually became convincing outside of Japan as well. Since the 1980s, many manufacturing companies in the US and abroad have adopted this philosophy. They converted their operations to implement lean production techniques and, consequently, were able to radically increase their competitiveness (Womack and Jones 1996). Some lean production techniques are:

1. Stopping the assembly line to immediately repair quality defects. While this usually is very disruptive for the process as a whole, there are several advantages to doing so: (1) the flawed processing step can be corrected right away, before numerous other assemblies have undergone the same treatment, resulting in additional defects; (2) it is substantially easier and less costly to discover and repair a quality defect early on in a process rather than at the end, after an assembly has been completed.
2. Pulling materials through the production system to meet specific customer demands, as opposed to building up inventories of work-in-progress and completed assemblies in anticipation of—often misjudged—customer demand.
3. Reducing the overall process cycle time by minimizing each machine’s change-over time, so that the economic benefit of mass production over single-piece production is reduced substantially, in turn making custom small-size batches easier to justify.
4. Synchronizing and physically aligning all steps in the production process so there is little wait time for people

or machines, and virtually no staging of partially completed products. (Especially items 2, 3, and 4 combined enable manufacturers to produce products quickly and thus meet fast-changing market demands.)

5. Clearly documenting, updating, and constantly reporting the status of all process flows to all involved, so each person knows what others do and understands the implications of quality of their own work on the quality of the process output.

Koskela (1992) argued for the application of lean production to construction. Howell et al. (1993) worked towards (4) synchronization of production by studying interacting subcycles. This paper specifically focused on items (4) and (5) which relate to making the production process transparent to those involved as specialty contractors on a project and helping them synchronize their activities. Item (1) has been shown to apply to construction by introduction of the ‘shielding’ principle (Ballard and Howell 1994, 1998). The applicability of (2) to construction is elaborated on in Tommelein’s (1998) paper on pull-driven scheduling and in Tommelein and Ballard’s (1997a) paper describing look-ahead planning by means of screening and pulling. Item (3) pertains to operations improvement based on work methods design. Ballard and Howell (1994) presented the concept of ‘first-run studies’ as a lean construction technique to test work methods, recommend improvements, and obtain productivity data prior to engaging in a construction activity with all resources mobilized. Much more research is needed in all these areas.

CONCLUSIONS

The specialty contractor’s view on job shop management has been presented in order to shed light on coordination requirements during project execution. Coordination is not addressed adequately by contract administrators or designers of organizational structures. The writers wish to advance understanding of construction at the process level where interactions and uncertainties are revealed so that production can effectively be managed. They are developing lean construction techniques to help create more successful project organizations.

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