WORKMOVEPLAN: DATABASE FOR DISTRIBUTED PLANNING AND COORDINATION

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ABSTRACT

Planning during construction is a distributed process that involves many participants because needed information is usually not found within one party but is spread out among parties. As projects are becoming more dynamic and complex, and the involvement of specialty contractors is increasing, well-structured communication and coordination are more than ever essential for a project to succeed. Nevertheless, few existing planning tools provide the means to facilitate these processes. To fill this need, a new tool is presented here. This paper describes a WorkMovePlan, a database program that has been created to systematically develop lookahead plans and weekly work plans. Weekly work plans are detailed to include labor and equipment assignments as well as space use. Together with lookaheads, these plans are automatically shared so planners can detect potential conflicts and prevent expensive adjustments later on site. WorkMovePlan's distributed, bottom-up approach to planning, which complements the current centralized top-down approach, radically differs from practices supported by existing computing tools. We are currently working with general contractors and specialty contractors to identify the possibilities provided by the interactive coordination of distributed work plans in order to better coordinate work.

KEY WORDS

distributed planning, coordination, scheduling, planning, space scheduling, conflict detection, weekly work planning, lookahead planning, Last Planner, WorkMovePlan, WorkPlan

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INTRODUCTION

An essential ingredient of a successful project is good communication and coordination between the project participants. Due to the large number of participants required by the increasingly complex and dynamic nature of today's projects and the fragmentation of the US construction industry, the need for well-structured communication and coordination has become more important than ever. Our view is that coordination efforts need to take place at the production level. This means dealing with logistic issues and work assignments, to include the specification of labor, equipment, materials, and space use. By contrast, owners and contractors increasingly rely on partnering sessions to improve communication, yet these sessions rarely get down to such specifics. Along the same line, general contractors that are assuming the role of coordinators of specialty contractors have adopted a contract brokering role rather than coordinating production (Tommelein and Ballard 1997). This exacerbates the fragmentation among participants.

As general contractors adopt the role of brokers and projects become technologically more complex, specialty contractors have become responsible for a large percentage—if not all—of the on-site and off-site production work. Coordination of their specialty work has become a major issue. Specialty contractors value a general contractor's quality of management and adjust their pricing accordingly (Birrell 1985). As a result, the general contractor may become less competitive when its quality of management deteriorates. In an attempt to become competitive again, the general contractor may try to further decrease its staffing on projects, thereby further decreasing its involvement in contractor coordination. This creates a vicious reinforcing loop, leading to further deterioration of the quality of management.

To successfully complete a project, a party that has a large stake in the project needs to (re)assume the role of production manager and guide the effort of coordinating specialty contractors. Traditionally, a general contractor took on this role of coordinator, but there have been situations where a specialty contractor took on that role. For instance, a mechanical contractor working as the prime contractor, and a traditional GC firm working as a subcontractor for them, successfully completed a Silicon Valley project (Rosenbaum 1997).

Coordination requirements can be divided into two tightly linked categories. First is the coordination of actual physical resources, e.g., material, equipment, laborers, and space. Second is the coordination of information. The coordination responsibility of the production manager is to "coordinate information regarding the coordination of resources." Jin et al. (1996) stress the existence of reciprocal dependence, as well as precedence relations and resource dependences in a construction project. In other words, information or output of one activity could affect the decision made for another activity and vice versa. Thus, continuous communication among the involved parties is needed to insure that as much relevant information as possible is made available to the party that requires it to make a decision.

A key document (paper-based or electronic) in describing construction information is the schedule. The planning process during construction is a continuous and complex process that involves many participants because needed information is usually not found within one party but rests with numerous involved parties (Cohenca-Zall et al. 1994). Therefore the "coordinator" is not only responsible for notifying all players of the assumptions and decisions that have been made, but the coordinator must also represent sets of alternatives for consideration during schedule coordination. The quality of a coordinated schedule depends on the timeliness, correctness, adequacy, and reliability of the data.

Distributed planning and coordination requires interaction. Realistic plans are produced by integrating plans provided by participants at all levels in the project hierarchy: the owner, GC, and subcontractors. The purpose of the coordinated planning system that is presented here, is not to eliminate face-to-face weekly or daily meetings, but to make them more efficient by judiciously disseminating available information to those parties that need it. Since involved parties can identify potential conflicts ahead of time of the meetings, the conflicting parties can study the problem beforehand and spend meeting time on solving problems rather than detecting them. This distributed approach differs from current practice and its supporting computer tools though it may more closely fill the needs of actual practice.

The proposed distributed planning system requires computers with networking capabilities in order to facilitate the timely generation and processing of information. The widespread availability of low-cost computers and (wireless) Internet network communication minimize the barriers to technological implementation of the system.

BACKGROUND

MULTI-TIERED PLANNING AND SCHEDULING

Planning is an incremental process, typically done in a centralized, top-down fashion. A general contractor first develops a master schedule that spans the whole duration of the project. The general contractor's superintendent then breaks it down with some detail into (3- or 4-week) lookahead schedules. Lookahead schedules drive the work to be done by specialty contractors. Whereas the master schedule usually takes on the form of a CPM bar chart, the lookahead may take on the form of a spreadsheet. Although the lookaheads are built based on the master schedule, an explicit link seldom is maintained between the two.

Specialty contractors create their own lookaheads. In turn, their foremen create weekly work plans that span one or at most two weeks into the future. It is not useful for them to detail their work further out into the future because numerous details remain to be tied down, many alternatives exist, and all are subject to uncertainty. Foremen plan their work and depict their plans at a level of detail that bears little or no relation to the GC's lookahead schedules, though, of course, work is supposed to be done to match those schedules. Thus, the link between the overall master schedule (project schedule) and the weekly work plan (production schedule) is lost. Weekly work plans reflect specifically how, where, what, and by whom work is likely going to be done, so they are extremely valuable in terms of articulating the production system that will be employed by those doing the work on site. Nevertheless, foremen reveal their weekly work plans—if at all—to their crew but rarely to others on site. Accordingly, an opportunity is lost to identify conflicts before work starts or reschedule work so that all parties on site would be better served.

The method presented here is based on a tiered planning approach, where weekly work plans are integrated in a bottom-up fashion, in order to identify conflicts and coordinate site work.

SPACE SCHEDULING

Space scheduling (Tommelein and Zouein 1993) refers to the allocation of site space concurrently with the scheduling of activities. Space scheduling has been gaining prominence as an area for applied research in construction. Thabet (1992) blocked out rooms for the exclusive use by a single trade and used this added constraint to make schedules more realistic. Riley and Sanvido (1995) categorize space uses into areas and paths. They identify construction space uses such as layout areas, unloading areas, material paths, staging areas, personnel paths, storage areas, prefabrication areas, work areas, tool and equipment areas, debris paths, hazard areas, and protected areas. Akinci et al. (1998) created a framework for characterizing the space needs of installation activities using orthogonal parallelepipeds and illustrating schedule impacts once a space-interference is detected.

UNCERTAINTY AND INTERDEPENDENCE

As most production tasks carried out on site require some prerequisite tasks and some follow-up tasks, the random variations in the start- or completion date of a task will affect those of other tasks. This effect amplifies when tasks belong to a "parade of trades" (Tommelein et al. 1999, Choo and Tommelein 1999a). Negative variation (output less than average) in a single parade may propagate throughout a project and ultimately delay the overall project completion date. Consider an example parade of trades as shown in Figure 1. The two numbers in each box represent the number of outputs generated by the corresponding trade, and each number has a 50-50 chance of occurring in a given time interval. These two numbers are used to simulate output variance (see Tommelein et al. 1999). Figure 2 shows the line of balance generated for a single instance of the simulated parade. Since a downstream trade can work only on output produced by the upstream trade, negative variation will propagate through the parade.

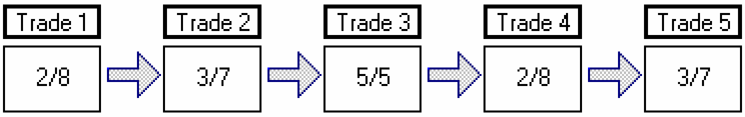

Figure 1. Five successive trades

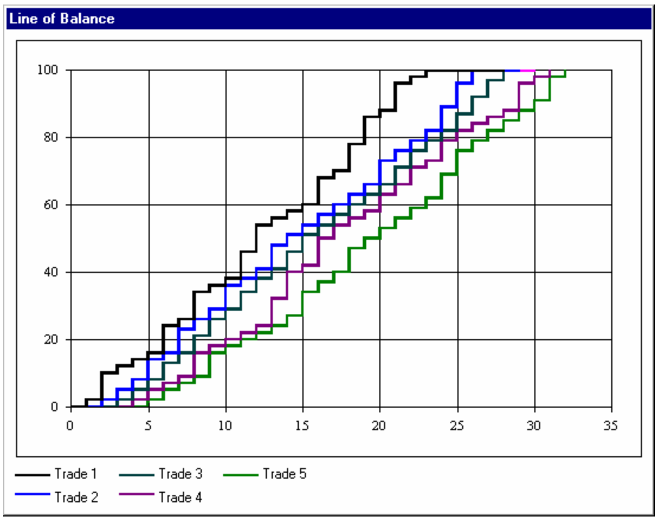

Figure 2. Line of balance for five successive trades

Positive variation in principle can result in an earlier finish than anticipated, which in turn can result in an earlier start of a successor. Nevertheless, positive variation is rarely taken advantage of. When subjected to variation, systems tend to exhibit deteriorating performance. One reason is that it may not be possible to notify a succeeding trade of the opportunity to start work earlier than planned. Another reason is that the trade may not be able to mobilize the necessary resources on site to carry out the work when needed early. This is not to suggest that trades should always have unused additional resources on site ready for an unanticipated opportunity to start work early (though excess production capacity is desirable in situations of variability because it makes it possible to increase the reliability of work flow). It is to suggest that if an earlier finish can be anticipated during the lookahead or weekly work planning process, it should be communicated to other participants as soon as possible. The presented WorkMovePlan model provides this capability. This may give the succeeding trade enough time to get ready and thus take advantage of positive variation.

It is also important to note that regardless of how predictable and reliable any one trade is, the parade as a whole is plagued by variation from other trades. If all trades were paid in terms of throughput, there is little incentive for a single trade to become reliable because a single unreliable trade will hamper the performance of the parade. If each trade were paid in terms of amount output it generated, the owner will be paying for work-in-process (WIP) which really is of little value to them. Thus, all trades will have to become reliable in order for a parade to succeed. The same rule can be extended for a project that comprises multiple parades of trades. Our work will further investigate these issues of interdependence and uncertainty, and their impact on overall performance.

WORKPLAN

Choo et al. (1999) developed WorkPlan to assist field managers in closely monitoring work packages in order to achieve production level planning and control according to the Last Planner method (Ballard and Howell 1994a, 1994b). WorkPlan guides production managers in creating a quality weekly work plan. The current implementation of WorkPlan comprises lookahead planning capabilities as well.

In WorkPlan, a work package is the scheduling unit. A work package is a definite amount of similar work to be done (or a set of tasks) under the responsibility of a single production unit (PU) (Ballard 1999) in a well-defined area, using specific design information, material, labor, and equipment, and with prerequisite work completed. Each work package has constraints that must be satisfied before it is released for construction in order for it to be likely carried out successfully and without interruptions. These constraints are categorized in five types, as constraints on contract, engineering, material, labor, equipment, and prerequisite work.

WORKMOVEPLAN

WorkMovePlan (Choo and Tommelein 1999b) combines the Last Planner methodology, implemented in WorkPlan, with space scheduling and web posting capabilities. The program also provides users with the ability to query other participants' plans and to exchange data. This is to allow for the coordination of schedules produced by different parties involved in a single project. The details of the space scheduling and web posting capabilities are explained in Choo and Tommelein (1999b, 2000).

The information exchange capability in WorkMovePlan allows the user to automatically access the latest scheduling information provided by other project participants. By viewing other participants' schedules, the planner may be able to anticipate conflicts. This gives the planner the option to plan around or to coordinate work with the other parties involved in the conflicts, so that conflicts can be alleviated or avoided altogether. The detection of conflicts is currently done manually by the planner. Once a conflict is detected, the specialty contractor can type in the information regarding the conflict and the parties involved. The information is then automatically passed on to those affected. Study is underway to determine which conflicts can be automatically detected.

DISTRIBUTED PLANNING AND COORDINATION

COORDINATED PLANNING

Since WorkPlan and WorkMovePlan were developed to schedule the work of a production unit, whether it is a general contractor or a specialty contractor, the programs usually contain information about more than one project. Figure 3 presents a sample case. Project A is composed of GC1, SC1, SC2, and SC3 (GCi refers to a general contractor and SCi to a specialty contractor). Project B is composed of GC2, SC3, SC4, and SC5. Thus, SC3's WorkMovePlan will contain information regarding Project A and Project B at the same time. WorkMovePlan's coordinated planning capabilities automatically direct project information to the corresponding parties by selectively matching information to projects.

Many project management tools in use today are single-project based, but when general contractors or specialty contractors are involved in more than one project, they have to be able to see across projects in order to trade off conflicting objectives. Project objectives are usually specified in terms of product quality, cost, and schedule whereas company objectives pertain to the overall, on-going production process and are expressed in terms of profitability, continuous workflow, steady employment, reputation, and process efficiency.

Consider the following example of a tradeoff that arises when more than two of the same type of resource exists, e.g., two welders with a different skill level, in a company that has two projects going on simultaneously. The company's planner will have to decide whether to put the better-paid, more highly-skilled worker as opposed to a lower-paid, less-skilled worker on one project or another. Quality- and time-wise it may be better to put the highly-skilled worker on one project but, depending on the pace of the project and the specific project needs, profit-wise and in terms of labor force development it may be better to put the less-skilled worker there. Therefore, the ability to view the work both from the project perspective as well as from the production perspective is very important.

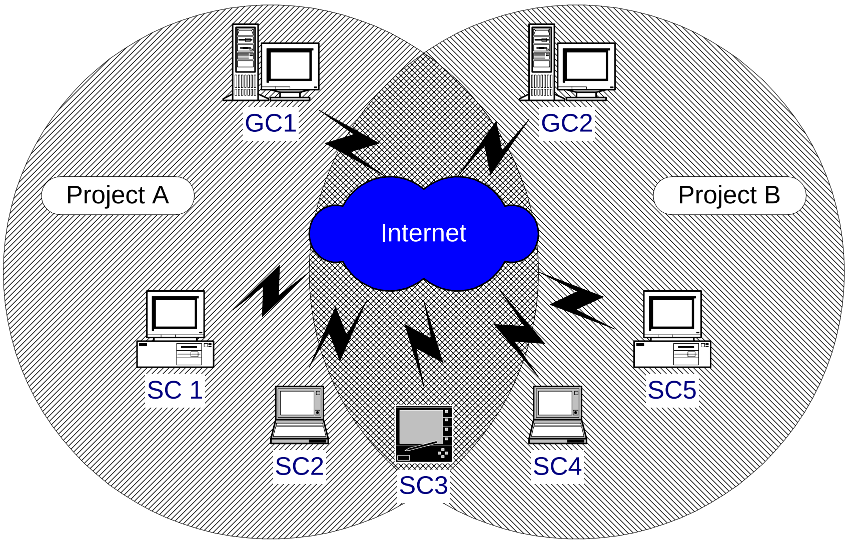

Figure 3. Coordinated planning scheme for multiple projects

WorkMovePlan also supports the project view by allowing the vertical integration between the master schedule, lookaheads, and weekly work plans. By maintaining an explicit link between the between the work description posted on the master schedule, lookaheads, and weekly work plans, a work package at the production planning level can be traced back to its parent work package at the project level.

A work package at the master schedule level is usually divided into one or more detailed work packages at the lookahead level. In turn, a work package at the lookahead level can also be divided into one or more work packages at the weekly work plan level. Therefore, a work package at a higher level schedule (parent WP) is composed of multiple work packages at a lower level schedule (child WP). A child WP must contain information about which parent WP it is a part of. For instance, a parent WP can be 'build concrete wall' and the child WPs of it can be 'place formwork', 'place rebar' and 'pour concrete', all pertaining to the wall.

Work is said to be 'out of scope' when a work package in the lookahead or weekly work plan cannot be traced back to any parent WP. It is important to avoid scope gaps or scope overlaps, so that all work performed on site can be traced in the planning hierarchy. Out of scope work packages would require a change order or at least an appropriate notification before work can begin.

CONFLICT DETECTION

The coordinated schedule can be used to detect incompatibilities before conflicts arise on site. A sample case next describes the types of conflict that can be anticipated during schedule coordination. The coordinated schedule consists of two parts. The first part is the coordinated weekly work plan, which shows the assigned dates and number of hours for labor and equipment associated with work packages. The second part is the project layout that shows spaces being used by each specialty contractor. Figure 4 illustrates this sample case. The left side shows the plan view of the first floor of a multi-story building whereas the right side shows the cross-section view marked A-A. For ease of explanation, three trades, HVAC, electrical, and drywall contractors are chosen. The drawing is simplified to show objects that belong to these trades. The drywall contractor is responsible for installing wall partitions as well as the ceiling grid and panels. The cross-section view shows HVAC duct in the plenum space. The light fixtures are mounted in the ceiling grid. Both the ceiling grid and the HVAC ducts are suspended from the floor slab of the story above, so there is no physical connection between the panels and the ducts.

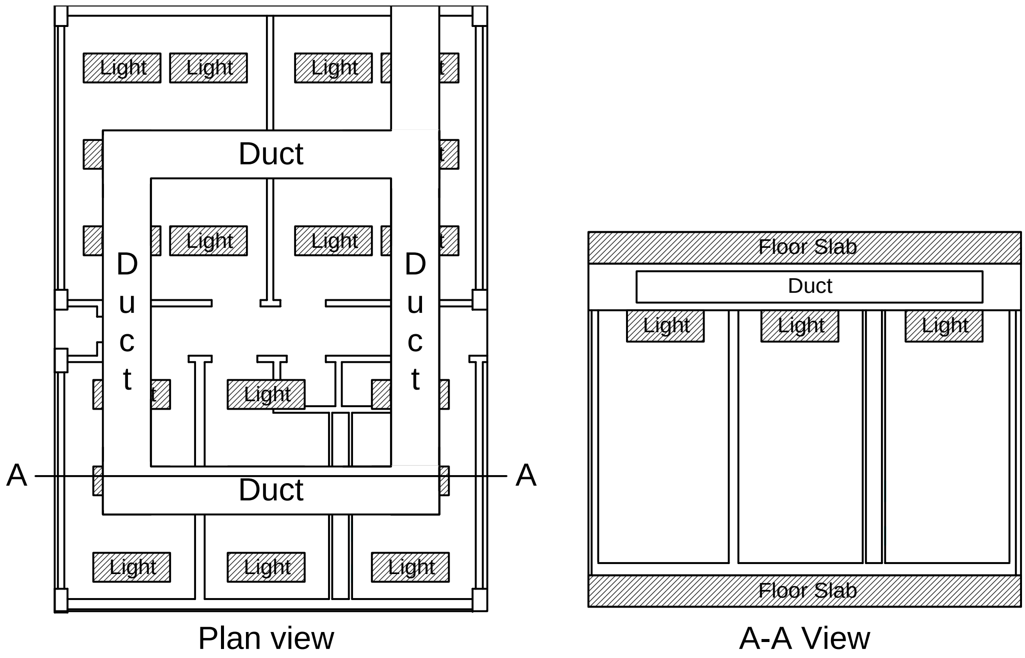

Figure 4. Plan and cross-section views for example case

Taking access constraints into account, one can infer from the drawing that the sequence of activities should be "install ducts", "install ceiling grid and panels", and then either "install light fixtures" or "install wall partitions" thorough out the floor. Thus, the HVAC contractor needs to start first, and be followed by the drywall contractor, and then either the electrical or the drywall contractor.

Many types of conflicts have the potential of occurring and could be anticipated by coordinating schedules. A first potential conflict pertains to prerequisite work. If the drywall contractor is scheduled to put in a ceiling before the HVAC contractor is finished, the HVAC contractor will have to take down part of the ceiling grid and panels in order to gain access for their work. Also, if the drywall contractor is scheduled to put in the wall partitions before the HVAC contractor is finished, then the HVAC contractor's work will be hindered when trying to put in a duct that goes above those walls. These prerequisite work conflicts are not hard constraints because they involve activities that are structurally independent, but they are preferred work sequences to allow for optimum work conditions.

A second potential conflict pertains to sharing resources such as laborers and equipment. Each specialty contractor brings a unique work force to the site so it is practically impossible for a person to be assigned to work packages belonging to different contractors. But there is a potential for conflict involving shared equipment, e.g., a crane or an elevator. Assume that the material laydown area is outside of the building due to lack of space inside the building, and material needed for each trade must be brought in to the corresponding floor using an elevator. By assigning the elevator as required equipment in their weekly work plan, the HVAC- as well as the drywall planner could recognize that coordination of its use is required. As is seen in Figure 5, although no conflict is anticipated for construction work between the two contractors, the material-handling schedule can result in a conflict if it is not coordinated beforehand.

HVAC subcontractor

Project No / Cost Code	Project Name / Assignment	Name / Desc	(Apr) 16	17	18	19	20	21	22
P1000	Sample Project								
100	Install duct								
		James Choo			8	8	8		
		HVAC							
		Elevator		4					
		Rented							

Drywall subcontractor

Project No / Cost Code	Project Name / Assignment	Name / Desc	(Apr) 16	17	18	19	20	21	22
P1000	Sample Project								
200	Install ceiling panels								
		Iris Tommelein				8	8	8	
		Drywall							
		Elevator		4					
		Rented							

Figure 5. Weekly work plan of HVAC and drywall contractor

A third but not a minor potential conflict pertains to sharing space. One of the first duties of a superintendent on a new project is to prepare a job layout (Peurifoy 1956) and field supervisors spend a large portion of their time managing that layout. By contrast, construction managers have been treating space scheduling secondary to scheduling of other resources. Figure 6 shows that by explicitly identifying space use, trade interference may be identified. Although the HVAC- and the drywall contractor will work in different rooms, both will use the corridor for access to deliver materials and equipment to the work face. This shared space use does not necessarily result in conflict. Each contractor may need to use the access path only a few times a day and leave it open the rest of the time. But by having information about which contractors will share the use of an access path, they can coordinate this use among themselves and thereby avoid conflict. Conflict detection in WorkMovePlan is a manual process where the planner needs to compare its space schedule versus those of other contractors and then determine what type of changes need to be made.

The responsibility for coordination does not rest on a single party such as the GC or a specialty contractor, but rests on several parties involved in a project. If the involved parties cannot reach a decision, a decision-maker needs to step in. A representative of the owner, a construction manager, or a superintendent can take on the role of decision-maker depending on the decision that needs to be made. The project coordination system represents and distributes information about resource schedules but solutions must come from people on the job.

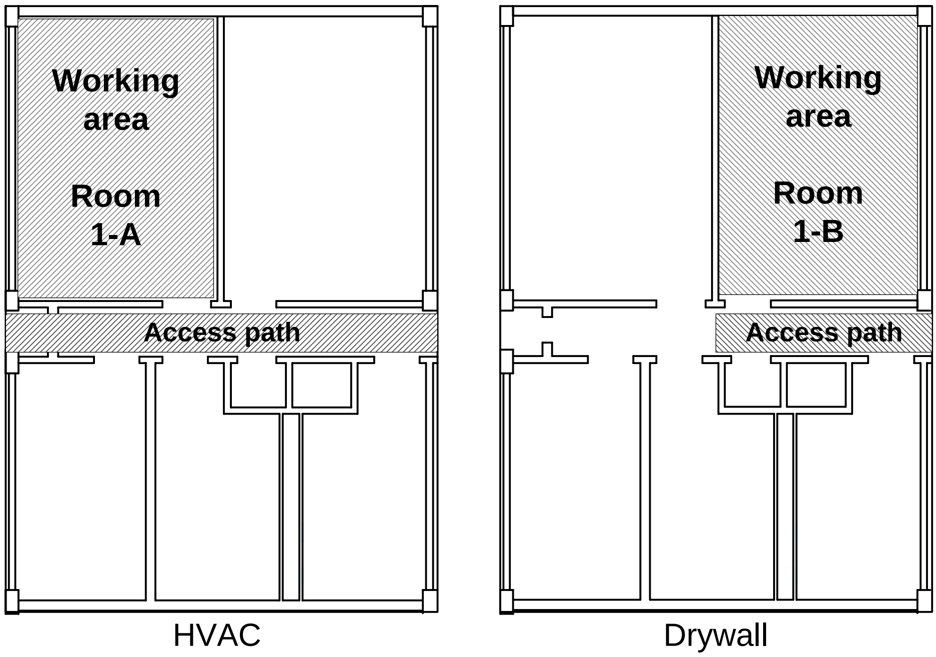

Figure 6. Site Layouts for April 19th for Schedule in Figure 5

Left: site layout for HVAC contractor; Right: site layout for the drywall contractor

OUTSTANDING ISSUES

The described method for distributed planning and coordination and the associated computer tool, WorkMovePlan, are under development. This paper presented an overall picture of the methodology being pursued and the features implemented in WorkMovePlan. Several questions need to be answered before the distributed scheduling system can be fully implemented. The first question is "What level of schedule detail is adequate yet useful for various parties?" Since the schedule serves as a communication tool in the distributed planning system, the information represented in it must be explicit enough to be comprehensive for other parties yet hide enough detail to protect each company's cost or other proprietary information. The second question is "Will parties agree to detailing their schedule and sharing it with others?" Providing a detailed schedule to others may commit that party to perform exactly what is in the schedule. Parties may be afraid that this will get them into claims and disputes if they are unable to deliver. Schedules (especially those showing much detail) are always subject to variability. Production system allowances—rather than legal threats—must be made to accommodate this. CPM schedules are all too often being misused in this way. However, if the planning system is reliable so that what is scheduled can be delivered, there is less of a chance for a claim or dispute. If claims or disputes do occur, the party that has kept a tight record on the issues at hand will be able to present factual data in support. The third question is "What is the impact of distributed planning and coordination on the overall system?" Planning is only one managerial task in administering a construction project. The impact of distributed planning and coordination on current practices regarding contracts, accounting, or project controls, remains to be studied. The fourth question is "How do we measure how well a schedule is coordinated?" A measure is needed to gauge how well a schedule is coordinated so that project participants can cooperate in improving performance and be rewarded accordingly. This measure may reflect the number of detected and avoided conflicts, and the number of conflicts arising during project execution. More work is to be done is this regard. .

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