INFORMATION FLOW INTEGRATED PROCESS MODELING

Qian Chen[1], David K. H. Chua[2], and Yuanbin Song[3]

ABSTRACT

In recent years, construction management has paid considerable attention to lean production, a philosophy that attaches great importance to flow issues and emphasizes the need to balance flow and conversion improvements. This paper presents the Information Flow Integrated Process Modeling (IFIPM) technique, which implements four procedures: (1) establishing information dependencies by using IDEF0 modeling method, (2) identifying information loops and conflicts in process relationships, (3) resolving information loops/conflicts, and (4) improving and re-computing the CPM schedule. This technique is capable of making information flows more explicit. As a result, the implicit information dependencies between construction activities can be made more obvious to all project participants and can be taken into consideration during process planning and scheduling. In this way, both the project process schedule and coordination among specialty subcontractors can be improved.

KEY WORDS

Lean construction, information flow, coordination, specialty subcontractor, and CPM

---

[1]   Ph.D. Candidate, Building Construction Department, Virginia Polytechnic Institute & State University, Blacksburg, VA 24061, 540/231-9877, FAX 540/231-7339, qchen@vt.edu

[2]   Associate Professor, Department of Civil Engineering, National University of Singapore, Singapore 117576, 65/6874-2195, FAX 65/6779-1635, cvedavid@nus.edu.sg

[3]   Ph.D. Candidate, Department of Civil Engineering, National University of Singapore, Singapore 117576, 65-6874-4643, FAX 65-6779-2248, engp0361@nus.edu.sg

INTRODUCTION

In recent years, industrial practice and academic research have attached great importance to the information management of AEC projects. In fact, much progress has been achieved in modeling and coordinating information, as well as in applying the emerging information technologies (Froese 1996; Mokhtar et al. 1998; Back & Moreau 2000; Hegazy & Ersahin 2001; Giandon et al. 2002). Regardless of such progress, however, in current construction practice the management of information still frequently falls below an acceptable level. By more efficiently managing the flow between conversion processes, *lean construction* provides a method for improving the efficiency of any construction project. This study investigates the possibility of utilizing the concept of flow improvement to enhance the efficiency of the construction process.

From the perspective of flow management, an adverse construction schedule can result from three basic information-related issues. First, when predominant scheduling methods like CPM and PERT are used, the information inputs/outputs required by construction processes often are not explicitly represented in the process planning stage. As a result, information constraints are frequently difficult to incorporate logically into the process network. Second, information dependencies among processes often are less explicitly considered. Consequently, during the detailed design and construction stages, shortages, delays, and unnecessary loops of information flows occur frequently. Such flow uncertainties are difficult to detect, particularly in a large-scale project that involves many designers and constructors. Third, as a result of poor communication techniques and insufficient awareness, information required by such long-lead processes as procurement and fabrication often cannot be provided in a timely fashion by other project parties. These problems often make the construction schedule difficult to maintain, with the most common results being the delay and even suspension of site work.

Numerous studies on project information modeling have been conducted by the construction industry in an attempt to improve information management. However, less attention is paid to improving the information dependencies among construction activities. This paper proposes use of the *Information Flow Integrated Process Modeling* (IFIPM) technique to explicitly incorporate into construction planning an efficient, streamlined flow of information. With such an explicit representation of information flows, dependencies between the construction processes can be more clearly expressed, and thus the process planning can be optimized. Furthermore, the scheduled commitment between various participants can be improved and construction productivity enhanced.

LITERATURE REVIEW

The construction industry has developed various integrated information models to abstract various domains of AEC projects. The *Integrated Building Process Model* (IBPM) attempted to use the IDEF0 modeling technique to represent the "essential functions" information required to design, plan, construct, and operate facilities (Sanvido et al. 1990). Song and Chua (2003) developed the *COSEE Model* to integrate product, process, and space by referencing the same kernel, the component state network, in order to verify the temporal and spatial consistencies in project schedules. The *ICON* (Information/Integration for

CONstruction) project studied the feasibility of using an object-oriented database to develop an information framework for integrating design and construction information from different AEC domains (Aouad et al. 1994). The **Building Project Model** (BPM) provides a conceptual modeling framework for integrating product, activity, and resources (Luiten 1994). The **Information Reference Model for AEC** (IRMA) monitored construction information by studying the reference mechanisms of integrated project aspect models (Luiten et al. 1993). All of these modeling studies investigated the capturing and representing of information in AEC project management and indicated the significance of integrating project information from multiple domains.

Several studies have shown that there are complex information dependencies between project processes. To improve process control, the Dynamic Model (Alexander 1974) incorporated feedback information. The Structure Analysis and Design Technique (SADT) (SofTech Inc. 1979) and the Workmap Model (Kartam et al. 1994) illustrated the interrelationships and interdependencies among processes from an informational aspect. To detect information bottlenecks and infer the potential for failure propagation, the Virtual Design Team (VDT) Project provided an agent-based simulation tool to abstract the information dependencies between concurrent processes (Kunz et al. 1998).

From the viewpoint of lean construction management, ameliorating the information flow between processes is as important as improving the construction conversion activities, an awareness that can be traced back as far as the 19th century (Walker 1985). However, total construction productivity cannot be optimized by improving the conversion efficiency alone. Many problems can arise from missed or misunderstood dependencies between processes (Park and Cutkosky 1999). However, the most prevailing scheduling tool, CPM, seems to concentrate much more on construction processes than on the flow between such processes, and in process scheduling in particular information interdependency is considered far less often. Although CPM can model the information requirements of process constraints, the sources and the destinations of the information are seldom represented. Unfortunately, most of the integrated information models developed by the previous studies focus on representing the relationships between different domain systems rather than on providing systematic procedures to evaluate their information flows.

This paper focuses on investigating the feasibility of improving construction schedules by incorporating information flow into the process network. First, a case study is introduced to illustrate scheduling problems that can arise from poor information flow. Second, the original project process system is presented and the information dependencies are identified using the IDEF0 method. Third, after incorporating information dependencies into the CPM schedule, the information loops and related conflicting process relationships are detected. Finally, the original schedule is improved to eliminate conflicts concerning information flows.

CASE STUDY

The company in the case study is a small-sized specialty subcontractor, which adopts a design-build delivery system to produce a variety of structural glass wall, skylight, and canopy projects. A typical glass wall project can be divided into three phases, namely design, fabrication, and installation, all of which are interrelated. In the first phase, designers produce shop drawings complying with all the requirements, architectural/structural drawings, and

specifications from both the clients and project architects/engineers. The fabrication process is often broken down into several work packages, which are frequently sublet to the external qualified fabricators. The glass wall specialty subcontractor is responsible for providing to the fabricators in a timely fashion all fabrication drawings and specifications. The installation phase also is comprised of several sub-phases, which are sequenced according to the physical laws that govern installing the glass wall product. Installation cannot start until all required resources are ready on site and an appropriate workspace is available.

Such a project typically involves extremely information-intensive in-house design and requires much site information; therefore, it is quite susceptible to delay problems. Additionally, due to the tight schedule, concurrent engineering policies are often applied, which in turn increase the information dependencies among the processes. Unfortunately, when information dependencies are not planned for adequately, the shortened time that results can often be consumed by critical information delays. Although the sequences of the processes are familiar to the glass wall specialty subcontractor, historical schedule data show that four types of schedule problems repeatedly occurred. These problems involve:

- Delayed input of design information from other participants,

- Delayed approval resulting from occasions when the review authority asks the contractor to complement and amend shop drawings in order to comply with other subcontractors' designs,

- Fabrication suspension that arises from waiting for the required as-built information or site measurements, and

- Installation interruption due to fabrication delays, errors, and rework.

Analysis of these historical cases indicates that many such problems arise from a failure to consider information constraints in the construction schedules. The following sections depict systematic procedures to detect the conflicts concerning information flows and provide strategies for removing these conflicts.

ARCHITECTURE OF INFORMATION FLOW INTEGRATED PROCESS MODEL

The framework of the IFIPM modeling technique is shown in Fig. 1. The model includes four information processes/procedures:

1. Establish information dependencies,

2. Identify information loops and related conflicts in process relationships,

3. Resolve information loops/conflicts, and

4. Improve and re-compute the CPM schedule.

ESTABLISH INFORMATION DEPENDENCIES

The first step in implementing the IFIPM involves illustrating information dependencies between the processes. The IDEF0 modeling format is employed to facilitate the establishment of such information dependencies. Meanwhile, the IDEF0 model is capable of

clarifying the process hierarchy and revealing functional relationships between flows and processes.

```
┌─────────────────────────────┐
│        Original CPM         │
└─────────────────────────────┘
              │
              ▼
┌─────────────────────────────┐
│          Establish          │
│   Information Dependencies   │
└─────────────────────────────┘
       │               │
       ▼               ▼
┌──────────────┐  ┌──────────────┐
│Detect Conflicts│ │ Locate Loops │
└──────────────┘  └──────────────┘
       │               │
       └───────┬───────┘
               ▼
┌─────────────────────────────────┐
│      Resolve Information         │
│         Conflicts/Loops          │
│  ┌────────────┬────────────────┐ │
│  │  Improve   │     Change      │ │
│  │Process     │Precedence       │ │
│  │Hierarchy   │Relationships    │ │
│  └────────────┴────────────────┘ │
└─────────────────────────────────┘
               │
               ▼
┌─────────────────────────────┐
│     Re-compute Schedule      │
└─────────────────────────────┘
               │
               ▼
┌─────────────────────────────┐
│         Imporved CPM         │
└─────────────────────────────┘
```
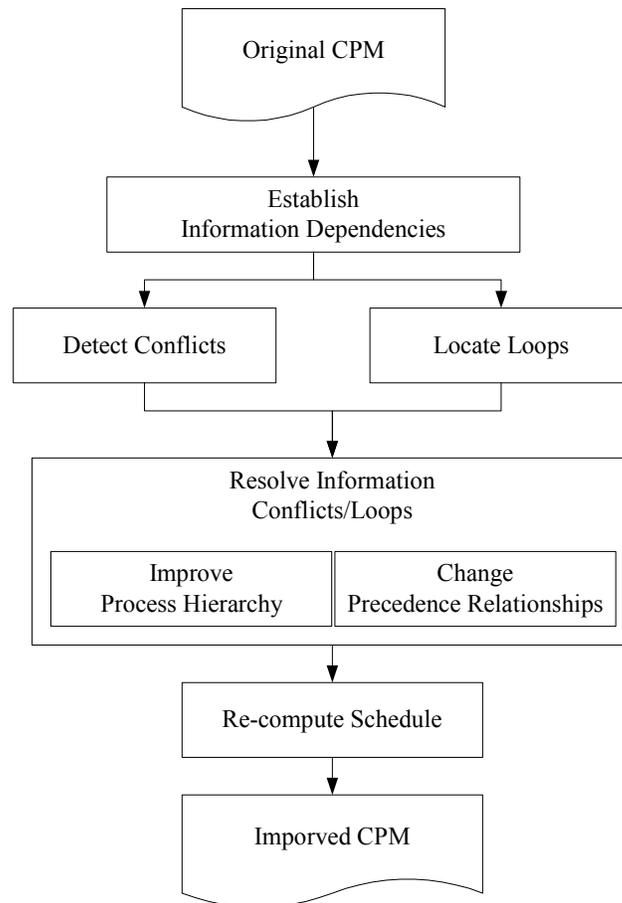
Figure 1: Structure of IFIPM

In order to explicitly depict their purposes, IDEF0 categorizes the information flows between processes in not only simply as input and output but also as mechanism and control. This paper further details the categorization of input, mechanism, and control into four subcategories: (1) constructability verification (C), (2) quality control (Q), (3) budget control (B), and (4) time control (T). With these detail categories, the purpose of the information flows can be more accurately defined in order to facilitate communication and coordination.

This paper uses several real cases to demonstrate application of the IFIPM technique for improving schedules. Due to space limitation, however, only the relevant project processes are illustrated. Fig. 2 demonstrates the process "Design the Glass Wall" using IDEF0 format. In addition to design activities conducted by the glass wall specialty subcontractor, two external review activities—"A22 Review Preliminary Design" and "A24 Review Detailing Design"—are utilized to maintain the completeness of both project subprocesses and information flows. The external parties involved can be the general contractor, architects, engineers, or design consultants, all of whom have direct information flow interfaces with the

glass wall specialty. In order to distinguish them visually, these externally-conducted processes are represented in Fig. 2 by dash-line boxes.
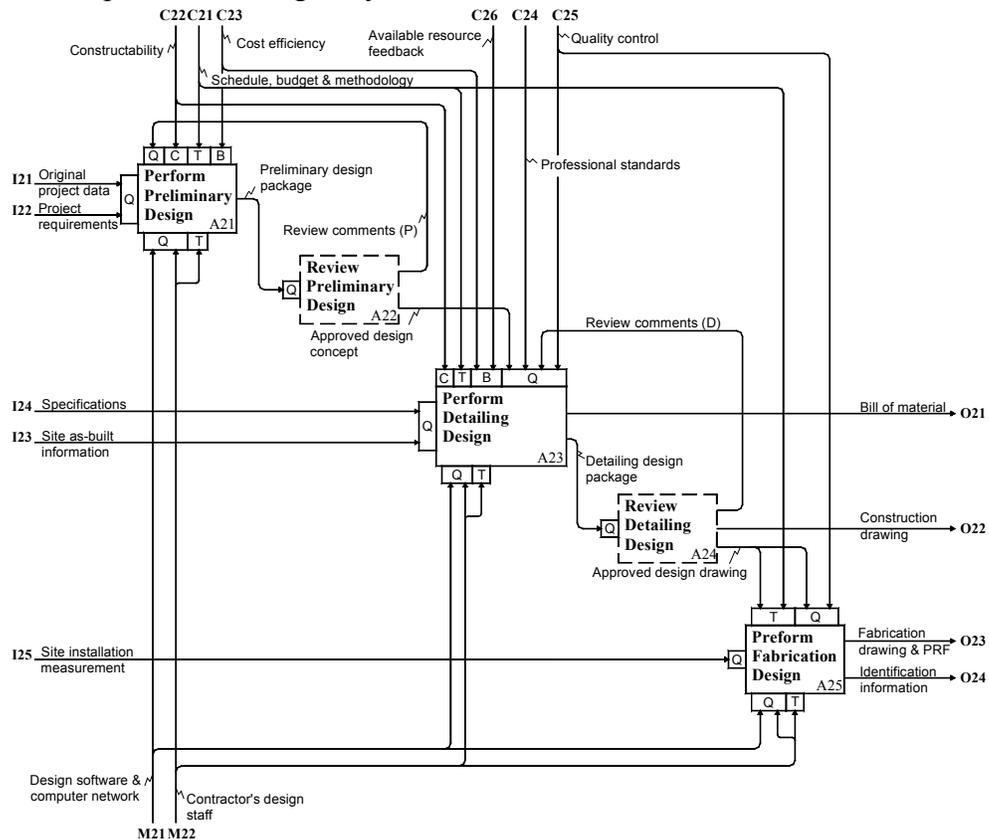

Figure 2: IDEF0 Diagram for "Design the Glass Wall" Process

As shown in Fig. 2, the shop drawing design requires various information inputs/constraints, with the most constrained design activity being "A23 Perform Detailing Design." This activity consists of two inputs and eight controls, in which I23: site as-built information is a very important input. As-built information derives not only from the available site surveys which indicate actual site conditions, but also from design information for adjacent works performed by other specialty subcontractors. These works will be executed on site and will change the site conditions.

Such an example occurred in the "One Raffles Link" Project, in which six different types of aluminum canopies incorporating lighting and sprinkler services were installed along the perimeter of the building. According to the architect's requirement, the external cladding that encloses the steel I-beams (which support the canopy) should be aligned with the joint-line of the column stone cladding. Fig. 3 shows this situation defined in the glass wall subcontractor's shop drawings.

Due to a delay in design information regarding the adjacent stone works, the shop drawings specified an incorrect surface level for the steel I-beams (107.040M). Based on this level, the steel I-beams were installed on site. However, when the shop drawings for the stone works were completed and made available, the glass wall specialty subcontractor

discovered that the actual level of stone joint-line was 107.159M, a figure that differed 100mm from the original supposition of 107.059M. As a result, the I-beams had to be removed and re-launched after correcting for the deviation. It is evident from this example that the lack of as-built information resulted in a conflict during the installation stage.
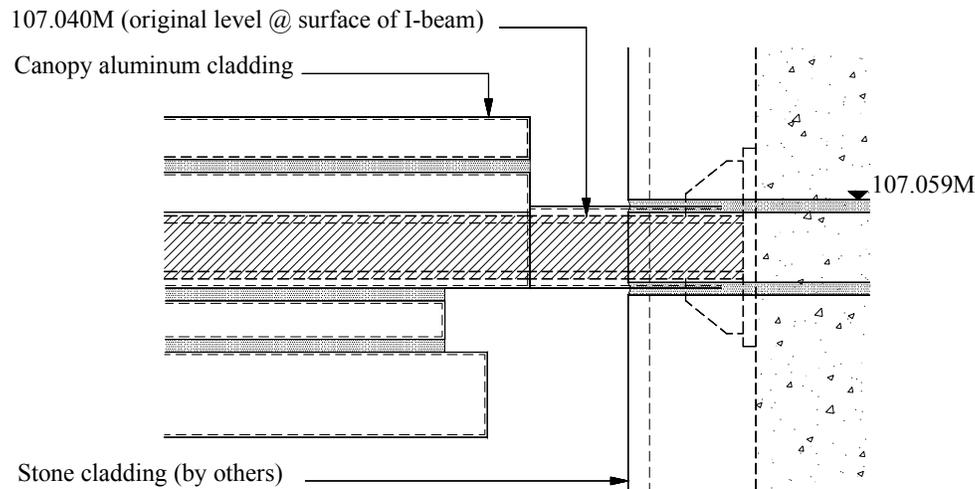

Figure 3: Front View @ Steel I-Beam Fixing Area

It is also noticed that there are two constraints or "Review comments" that are involved in backward loops. The longer the loops, the more adverse the effects suffered by the design process. Moreover, these loops arise from external parties conducting the review tasks. Therefore, they are out of the specialty subcontractor's control. From the subcontractor's viewpoint, in order to minimize the review time and the number of potential resubmissions, the only solution is to submit high-quality design drawings.

To use another example, "site installation measurement" is a critical constraint flow for "A25 Perform Fabrication Design." Sometimes, "site installation measurement," the side-product of "A5 Install the Glass Wall," can be involved in an iteration loop. Normally, glass products need long lead procurement and fabrication times, so the contractor will procure the fabrication much earlier than the installation. Under most circumstances, glass fabrication drawings have to be verified by the site measurement, which can be generated only after the steel framework has been installed by another contractor. In practice, the installation of steelwork occurs long after glass fabrication has begun. For example, if glass installation must begin May 1st, then for two months' lead-time the fabrication must be procured on March 1st. Accordingly, the glass fabrication design must be finished before March 1st. Nevertheless, in this example, the current schedule arranges for the steelwork installation to finish on April 27th. This means that the as-built information of the steel structure cannot be measured until April 27th. At this point a very risky loop occurs. If the contractor starts the glass fabrication early, this loop may result in an unsuccessful installation of glass due to tolerances from the steelwork installation. Alternatively, glass fabrication will be put on hold until the verification information becomes available. In either case, the original project delivery schedule faces delay.

IDEF0 modeling and analysis can help both the process decomposition and the identification of information flows between activities. Tracking of such information dependencies can retrieve some omitted process relationships, which may lead to additional constraints for affected processes. Therefore, amendment of the CPM schedule becomes necessary.

IDENTIFY INFORMATION LOOPS AND CONFLICTS IN PROCESS RELATIONSHIPS

Based on the IDEF0 models generated for the studied project system, an Information-CPM Network is built, as shown in Fig. 4.
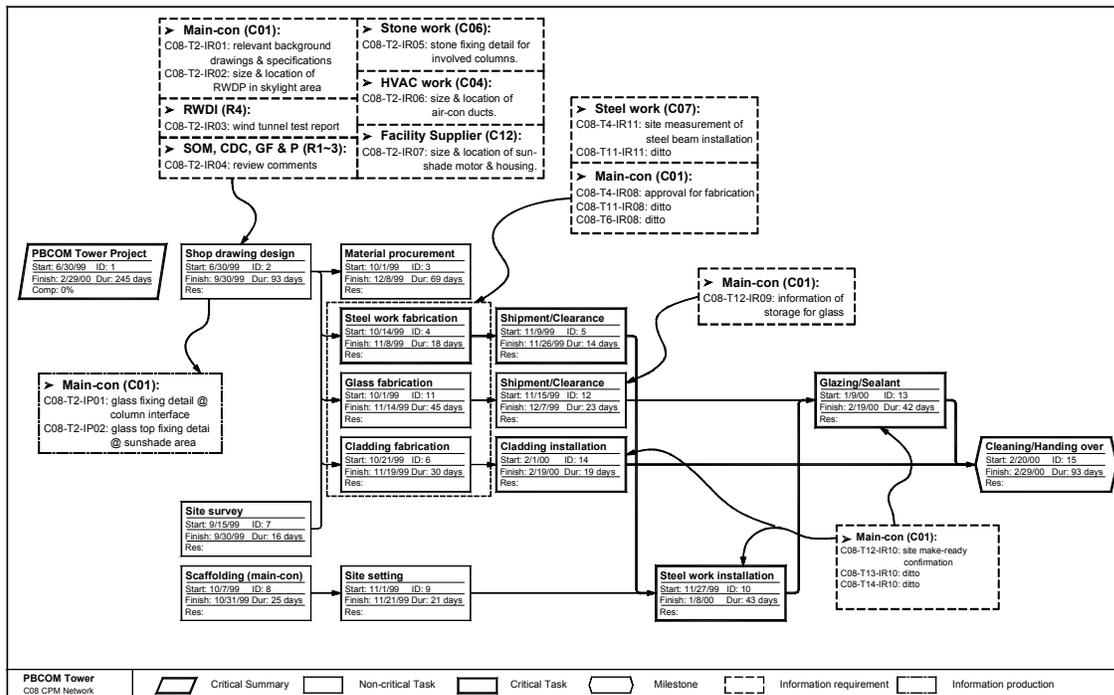

Figure 4: Information CPM Network

In this CPM network, the external information constraints relating to other project participants have been depicted in dashed boxes linked to the corresponding CPM activities. Herein, each involved party is given identification, such as CXX (for contractors) and RX (for consultants). By linking the information items to the tasks that require them or produce them, each information dependency between two tasks can be explicitly represented and located. For example, C08-T2-IR01 represents the fact that the information item IR01 should arrive before the contractor C08 executes the task T2. Similarly, C08-T2-IP01 indicates that the information item IP01 required by an external party is produced by task T2 in the contractor C08's CPM network. With the aid of the Information-CPM network, the information dependencies among the CPM tasks can be symbolized. Such explicit incorporation of information items into a CPM precedence diagram can further facilitate the coordination among the contractors for committing their schedules, according to which they can provide the timely information required by other participants.

Based on the above-mentioned information dependencies, some activities in different contractors' CPM networks should be connected due to information dependency relationships; in this way, the information loops and the conflicts in process relationships can be detected. However, the IDEF0 modeling method is not a suitable tool for detecting information loops. DSM, a useful method for sequencing the processes and analyzing information dependencies (Steward 1981), is involved in the proposed IFIPM to identify such information loops. Fig. 5 illustrates a real case in which information loops and relevant relationship conflicts occurred in the shop drawing design phase.
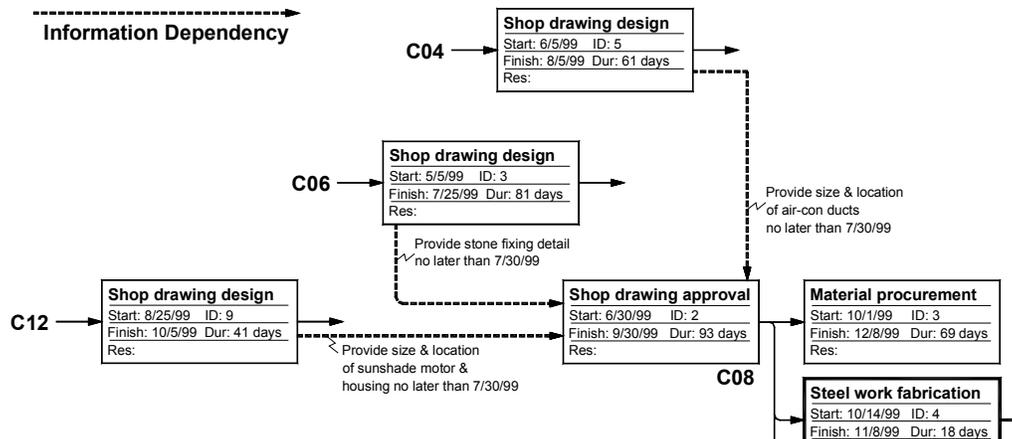

Figure 5: Information Loops in the Design Phase

As seen in the partial process network represented by Fig. 5, the contractors that whose activities are connected to the shop drawing design include the HVAC contractor C04, the stone works contractor C06, the glass wall contractor C08, and the facility supplier C12. In practice, it is very common that some design information can be generated much earlier than the approval date of the shop drawings, which occurs near the end of the design process. However, the general contractor often distributes the approved shop drawings of one trade to others that require them for information coordination after the approval date. In the above-mentioned case, the glass wall subcontractor C08 received the external drawings produced by contractors C04, C06, and C12 on July 25th, August 5th, and October 5th, respectively. However, in order to maintain the schedule, this same subcontractor's design task C08-T2 had to start on June 30th when the required external drawings had not arrived; as a result, since some information that should have been provided by the external contactors could only be estimated, in order to continue his work, the glass wall subcontractor was forced to base his own design configurations on his previous construction experience.

Since design time is tight, often the glass wall contractor must estimate some important parameters that were designed by external contractors but have not yet arrived. Unfortunately, if these estimated design parameters are finally found to be inconsistent with those in the drawings provided later by other contractors, the designer will be forced to reconfigure the affected parts. A much worse situation arises should these glass shop drawings be re-submitted for approval after correcting the inconsistencies. This procedure often takes time, which further delays the glass fabrication and installation. The worst situation of all occurs

when the consequent fabrication and installation have been performed according to inconsistent shop drawings. This ensures that the glass subcontractor must commit himself to rework.

A typical shop drawing design is often scheduled to fulfill both the overall project progress requirements and the special design duration. As for shop drawing design tasks, their programming is also driven by construction schedules. In addition, the CPM Method determines the task sequence by considering many other important constraints: physical, safety, resources, space, and so on. Therefore, in order to determine the best solution, the information loops and related conflicting process relationships should be carefully analyzed. The following subsection describes just such a solution.

ENHANCE THE CPM AND RE-COMPUTE CONSTRUCTION SCHEDULES

Process planning can be improved by using the following strategies to reduce or shorten the information loops:

1. Reprogram the process sequences,

2. Further decompose the processes to redefine the dependency relationships,

3. Redesign the project for decoupling the information interdependencies between processes/activities,

4. Add new processes for information coordination, and

5. Reduce the input of late-produced control information (like as-built information, site installation measurements) by innovative designs and more strict quality specifications and site control.

The information loops/conflicting relationships depicted in Fig. 5 can be resolved by applying the above-mentioned guides. Nevertheless, flexible implementation of these strategies is of essence. The proposed method involves subdividing some design processes into several stages and clarifying the critical intermediate outputs/requirements of design parameters.

As displayed in Fig. 6, C08-T2 "shop drawing design" can be broken into two sub-tasks: C08-T2-A "general design" (for the first submission), starting on June 30th 1999 and C08-T2-B "interface design" (for the resubmission), starting on July 30th 1999. The contents of the general design include such items that should be approved by the review authority: design concepts, detailing and interface design techniques, material selection, and assembly and installation methodology. Meanwhile, the designers should also state and highlight in the shop drawings all interfacial parts that may require future coordination and communication. In the interface design stage, in order to verify the consistency of the general design, such required coordination information as the stone fixing detail, the size and location of air conditioning ducts, and the size and location of sunshade motor and housing must be coordinated and committed.

On the other hand, the tasks involved in such a stage—C06-T3, C04-T5, and C12-T9— should produce this information at the right time. As shown in Fig. 6, the involved subcontractors should produce the design parameters of the interfacial parts and transmit

them no later than July 30th 1999 as they commit. In particular, the facility supplier C12 (whose shop drawing design was originally scheduled to start on August 25th 1999) must finish some design work before July 30th in order to produce the information "the size and location of sunshade motor and housing" requested by the glass wall subcontractor. Thereafter, the remaining design tasks can be put on hold and then resume according to the original schedule. Otherwise, the facility supplier must personally settle with the glass wall subcontractor C08 to determine when this information has to be produced. Such minor changes and shifts will successfully resolve any information-related task problems.
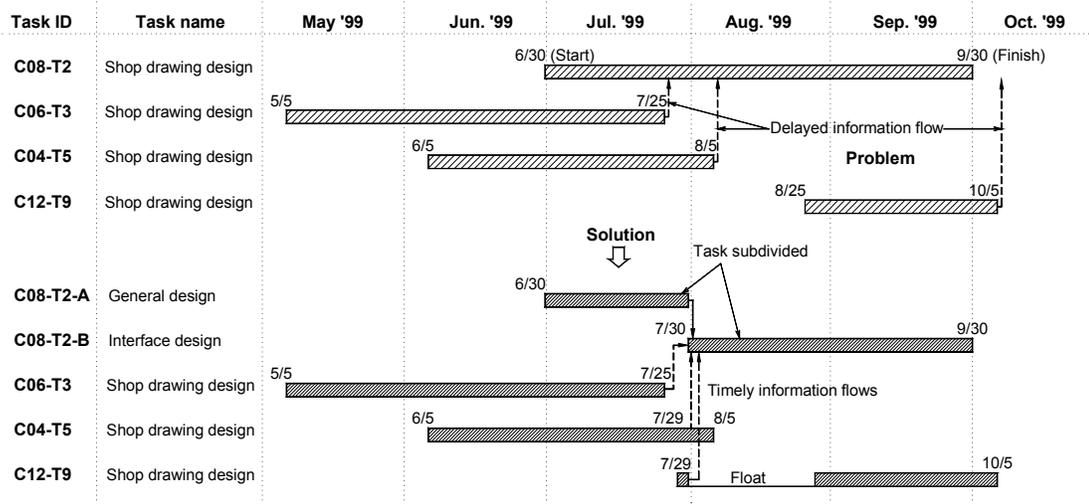
Task ID	Task name	May '99	Jun. '99	Jul. '99	Aug. '99	Sep. '99	Oct. '99
C08-T2	Shop drawing design			6/30 (Start)			9/30 (Finish)
C06-T3	Shop drawing design	5/5		7/25			
C04-T5	Shop drawing design		6/5		8/5	Problem	
C12-T9	Shop drawing design				8/25		10/5
				Solution			
C08-T2-A	General design			6/30	Task subdivided		
C08-T2-B	Interface design			7/30			9/30
C06-T3	Shop drawing design	5/5		7/25	Timely information flows		
C04-T5	Shop drawing design		6/5	7/29 8/5			
C12-T9	Shop drawing design			7/29 Float			10/5

Figure 6: Process of CPM Enhancement

CONCLUSIONS

This paper proposes a modeling technique, the Information Flow Integrated Process Modeling (IFIPM), to incorporate information flows into CPM planning. This modeling method further details and clarifies the relationships between the construction conversion processes. In this way, the conversion processes and information flows can be concurrently modeled on a consistent framework. The IDEF0 modeling technique is employed to identify the information dependencies between the processes, and the DSM is used to locate the information loops among the processes. This paper also presents the argument that improving process hierarchy and changing precedence relationships can reduce or shorten information loops and resolve consequent conflicts. In this way, the CPM schedule can be improved to optimize construction productivity.

Although many studies have been conducted to develop information models, less concern has been paid to explicitly representing the information dependencies between design and construction processes. The initial intention of this study is to investigate the feasibility of developing a modeling method to enhance CPM scheduling by identifying and clarifying the information flow between interrelated processes. It must also be noted that implementation of the lean construction philosophy could face great challenges in practice if planners and engineers are not equipped with practical and systematic tools for its application. The IFIPM is thus developed as a tool for guiding the AEC practitioners who wish to incorporate

information flows effectively into their construction projects. It also enriches the lean construction study by considering the additional effects of information flows on process planning and scheduling.

REFERENCES

Alexander, M.J. (1974). *Information System Analysis.* Science Research Associates Inc., Kingsport, Tennessee.

Aouad, G. et al. (1994). "Integration of Construction Information." *Final report,* University of Salford, Manchester, England.

Back, W.E. and Moreau, K.A. (2000). "Cost and Schedule Impacts of Information Management on EPC Process." *Journal of Computing in Civil Engineering,* ASCE, 16(2), pp.59-70.

Froese, T. (1996). "Models of Construction Process Information." *Journal of Computing in Civil Engineering,* ASCE, 10(3), pp.183-193.

Giandon, A.C., Junior, R.M. and Scheer, S. (2002). "Implementing Electronic Document Management System for a Lean Design Process." *In Proc. 10th Annual Conference of the International Group for Lean Construction,* Gramado, Brazil.

Hegazy, T. and Ersahin, T. (2001). "Simplified Spreadsheet Solutions. I: Subcontractor Information System." *Journal of Construction Engineering and Management,* ASCE, 127(6), pp.461-468.

Kartam, S., Ballard, G. and Ibbs, C.W. (1994). "Construction Models: A New Integrated Approach." *In Proc. 2nd Workshop on Lean Construction,* Santiago.

Kunz, J.C., Levitt, R.E. and Jin, Y. (1998). "The Virtual Design Team: A Computational Simulation Model of Project Organizations." *Communications of the Association for Computing Machinery,* 41(11), pp. 84-92.

Luiten, G. (1994). *Computer Aided Design for Construction in the Building Industry.* PhD thesis, Faculty of Civil Engineering, Delft University of Technology, The Netherlands.

Luiten, G. et al. (1993). "An Information Reference Model for Architecture, Engineering, and Construction." *Proc. 1st International Conference on the Management of Information Technology for Construction, World Science,* Singapore, pp.391-406.

Mokhtar, A., Bėdard, C. and Fazio, P. (1998). "Information Model for Managing Design Changes in a Collaborative Environment." *Journal of Computing in Civil Engineering,* ASCE, 12(2), pp. 82-92.

Park, H. and Cutkosky, M.R. (1999). "Framework for Modeling Dependencies in Collaborative Engineering Processes." *Research in Engineering Design,* 11, pp. 84-102.

Sanvido, V, et al. (1990). "An Integrated Building Process Model"*, Tech. Rep. 1,* CIC Research Program, Arch. Eng. Dept., Pennsylvania State University.

SofTech Inc. (1979). *An Introduction to SADT: Structure Analysis and Design Technique.*

Song, Y. and Chua, D.K.H. (2003). "COSEE: Component State Network Centric Model for Verifying Temporal and Spatial Consistence in Project Schedules", *20th International Conference: Information technology for Construction.* pp. 325-332.

Steward, D.V. (1981). The Design Structure System: A Method for Managing the Design of Complex Systems." *IEEE Transactions on Engineering Management,* 28(3), pp. 71-74.

Walker, A. (1985). *Project Management in Construction.* Collins P. and T. Books, London.