PROCESS MODEL PERSPECTIVES ON MANAGEMENT AND ENGINEERING PROCEDURES IN THE PRECAST/PRESTRESSED CONCRETE INDUSTRY

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Abstract

The preparation of detailed models of information and process flow by 14 member companies of the North American Precast Concrete Software Consortium has provided a unique window into the current management, engineering design and production operations in this industry. The modeling was performed using the authors' GT PPM process-modeling tool, within the framework of the consortium's effort to develop a Precast Concrete Product Model (PCPM) and to specify new integrated 3D modeling software. The paper opens with a comparative economic review of precast construction internationally and in North America, which reveals that the market share of precast construction in North American is relatively low. The models are analyzed and aspects of the underlying management procedures that they reveal are discussed, such as types of contracting arrangements, cost estimating, design outsourcing, engineering design communication, mold design, product diversity, and quality control. The results highlight aspects of precast management processes that may be re-engineered through appropriate application of information technology.

Keywords: Concrete, precast; Design; Construction management; Estimation; Quality control; Information Technology (IT).

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Introduction

Although precast concrete offers significant potential advantages in quality, speed of erection, and cost, its share of the overall building construction market in North America is very low (approximately 1.2%, PCI 2000), especially when compared with other industrialized regions. Figure 1 compares the share of reinforced concrete construction supplied by precast producers in the USA – only 6% – to those in European countries. The average across the European Union is 18%. Many factors influence the market share of precast concrete; most, such as labor costs, climate, and the relative costs of alternative construction types, are beyond the control of precast producers. An earlier investigation into the reasons for the small share of precast in the USA revealed that the two main reasons were a severe shortage of precast design personnel and that many contractors do not realize significant cost savings when using precast concrete systems (Arditi et al 2000).
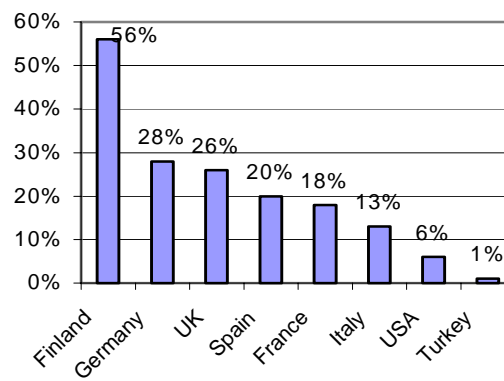

Figure 1. Percentage of total concrete production consumed in precast concrete construction, 1998 (PCI 2000).

Recognizing that significant improvements in the competitiveness of the precast industry might be achieved through integration and automation of their information-dependent processes, 23 North American producers formed the Precast Concrete Software Consortium (PCSC). The consortium's primary goals are to:

- re-engineer the information-dependent aspects of their business process, with emphasis on specification and development of integrated 3D modeling based engineering design tools, and

- integrate information flow throughout their business process, based on a building product model – the Precast Concrete Product Model (PCPM).

Reducing the engineering lead-time from award of contract until commencement of production, from a current minimum of six to eight weeks to just one week, was set as a target.

In their capacity as advisors to the PCSC, the authors developed a new process modeling methodology and software tool in support of the technical goals of the PCSC (for these aspects of the work see Eastman et al. 2001; Lee et al. 2002). The fourteen detailed process models developed using this new methodology and tool, besides supporting the above goals, provided extensive data that opened a unique window into the operations of the companies that built them. This paper explores the perspectives on the management and engineering procedures in the North American precast/prestressed concrete industry afforded by the process models. The authors' intent is to provide a record of the procedures, as they exist in the companies, based on analysis of the models and on the understanding gained in the course of their compilation.

The paper is organized as follows. First, the products, market and structure of the North American precast concrete industry are characterized. Next, the process modeling methodology and the software tool built to support it are briefly described. The heterogeneous detailed models that were collected and the methods used to analyze the data they contain are presented. That data is interpreted, applying wider understanding gained while working with the precast producer companies, and the similarities and differences in the management and engineering procedures common in the different companies are discussed. The issues cover cost estimating, contractual arrangements, mold design, product type, precast piece engineering, project and production scheduling, quality control and information flow.

An Overview of North American Precast Construction

Although the North American precast concrete industry produces technologically and architecturally complex buildings and building elements, its share of the construction market in general, and reinforced concrete in particular, is small in comparison with other industrialized regions. Table 1 shows the US market share of the industry for various building types (PCI 2000). The total is 1.2%. The largest single market is parking deck structures, with 1,010 m$, representing 12.9% of the market. In contrast, in Finland,

for example, 25% of all structural slabs and 11% of all building facades are precast (FCIA 2000, RTT 2000). The influences of cost and availability of other construction types can be removed from the comparison by considering reinforced concrete construction in isolation; precast construction consumes 7.9% of the concrete produced for construction in the US, compared with 70% in Finland, as shown in **Error! Reference source not found.**. (Note – the values in **Error! Reference source not found.** include concrete consumed for purposes other than construction, such as road-paving, and are therefore lower).

Table 1. US precast and total construction contracts, Year 2000, ($1,000,000) (PCI 2000)

Building Type (1)	Total Precast Construction Contracts (2)	Total Construction Contracts (3)	% Precast Share (4)
Public and Commercial Buildings	$3,346	$143,297	2.3%
Hotels, Motels and Housing	$352	$38,356	0.9%
Bridges	$640	$10,209	6.3%
Single-family Houses	$13	$175,296	0.0%
Other	$443	$46,063	1.0%
Total	$4,794	$413,221	1.2%*

*Neglecting single-family houses, the precast share is 2.0%.

The elements most commonly produced for building construction in the USA are double tees, hollow-core slab elements, inverted tee and ledger beams, spandrels, columns and façade panels. A few companies also produce complete modular building elements, such as bathrooms, hotel rooms and prison cells. Despite relative uniformity in the basic section profiles, there is no standard for element dimensions. Each company produces double-tees, for example, with different sets of basic dimensions. Production of façade panels, termed architectural precast, is technologically advanced. Façade panels offer aesthetic solutions with a complexity of shape and finish usually unattainable in cast-in-place reinforced concrete. Nevertheless, the volume of architectural precast is small: façade panels account for only 8.9% of precast production (Table 2), as compared with 25.7% in Finland.
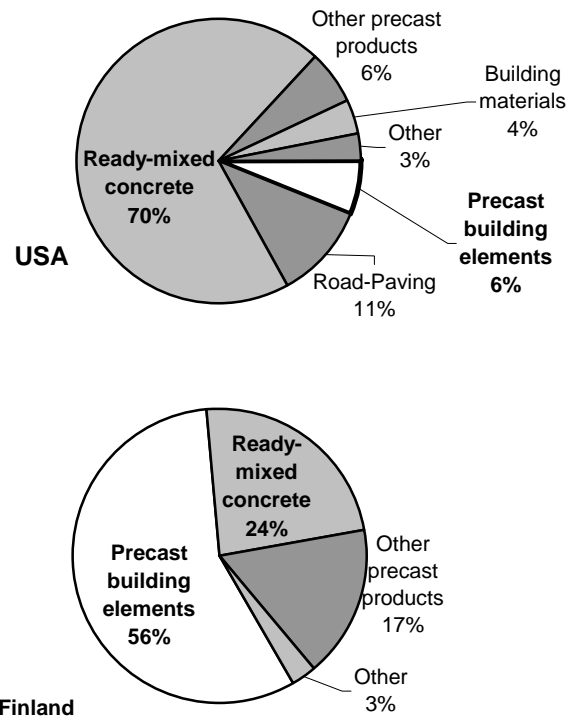
Figure 2: Concrete Applications in the USA and Finland (PCI 2000, FCIA 2000)

Table 2. Statistical comparison of US and Finnish
precast production (PCI 2000, FCIA 2000)

Precast Statistic	USA	Canada	Finland
(1)	(2)	(3)	(4)
Total Precast Building Sales ($1,000,000)	4,794	340	264
Wage-earning employees	33,170 (est.)	3,300	3,313
Total Precast Element Production (1,000 m^3)	9,060	-	972.4
Precast / Total Concrete Construction (%)	7.9%	-	70%
Architectural Precast / Total Precast (%)	8.9%	37%	25.7%
Structural Precast / Total Precast (%)	90.1%	63%	74.3%

Precast concrete plants serve limited geographic regions, restricted by the maximum distance over which

their products can be transported economically. Although many companies operate more than one plant, the

industry remains highly fragmented. The approximately 380 plants in Canada, the US and Mexico are operated by some 160 producer companies (PCI 2000).

Process Modeling Methodology and Tool

Preparation of a building product model requires detailed knowledge of the information requirements inherent in the processes that the model is intended to support (Eastman 1999). Process modeling, using graphical process modeling tools such as IDEF0 (Integration Definition For Function Modeling - NIST 1993), has traditionally been used as a starting point for eliciting and recording the terminology and scope of the universe of discourse. The CIS/2 development (Crowley and Ward 1999) and the COMBINE project (Augenbroe 1995) provide typical examples of projects in which process modeling was used in support of product modeling for construction projects (using IDEF0 and 'Combi-nets' respectively). In the precast domain, Karhu (1997) used SADT-charts (Structured Analysis and Design Technique - Marca and McGowan 1987) to model the design of facades for residential buildings, in preparation for developing a product model.

The PCC-IFC project (Karstila 2001) aims to expand the Industry Foundation Classes (IFC) model of the International Alliance for Interoperability (IAI) by developing a product model for precast concrete. In this work, an IDEF0 process model depicted 47 detailed activities. Information flow arrows carried only high-level labels - no details of information usage or flow were modeled. The model is a single, unified model, and describes only one process – the provision of precast components for buildings. It does not cover provision of entire building systems by the precast producer, and considers only one contractual possibility (in which the precast producer is a sub-contractor). This is evidenced by the clear separation between conceptual building design and precast design: negotiation and contract occur after building design is completed.

The methodology adopted for the process modeling stage in the PCSC effort differs from these efforts primarily in terms of two innovations:

- Instead of a 'committee' or 'interview' approach in which one unified industry process model is prepared, each company developed a distinct process model that most accurately described its own

process. The models express the diversity of business and management practice, rather than burying them in an 'all encompassing' unified model. As such, they are better suited to specification of industry software, which must cater to a variety of usage scenarios. Placing the modeling tools directly in the hands of the company experts also, ameliorates the problems associated with elicitation of expert knowledge (Hayes-Roth et al. 1983, Ranasinghe and Russell 1993).

- The level of detail of the models was deepened to allow explicit capture of the specific information items required by the process activities as input, the information generated by them, and the information flows between them. Models with this degree of detail are termed 'information-rich' models; in this form, they are the raw material for product model development. In the on-going work, the process models will be processed in a sequence of stages, resulting in a product model that can be validated in terms of its ability to support the original processes (Eastman et al. 2002).

This strategy led us to develop a purpose-built modeling tool, named GT PPM (Georgia Tech Process modeling for Product Modeling – Lee et al. 2002). The tool provides the graphic symbols and constructs for modelers to describe their processes, as in Figure 3, and provides the interfaces for capturing detailed information inputs and outputs for each process activity. It performs automatic consistency checking as a model is built, highlighting any information unavailable from upstream activities or not provided to downstream activities (Lee et al. 2002). The resulting models are machine-readable and can be analyzed automatically.

A standard data-dictionary and a top-level layer for a process model are each provided within the tool to ensure that comparative analyses can be performed across the individual company models. The data-dictionary defines the information item terms to be used in process activities, including synonyms to cater for the variation in terminology within the industry. The top-level model shown in Figure 4 defines the aggregate activities and flows that express the basic commonality of the precast process. Each modeler starts from the top-level activities, elaborating them into detailed activities (intermediate layers of

additional aggregate activities are allowed). Both the data-dictionary and top-level model are arrived at a

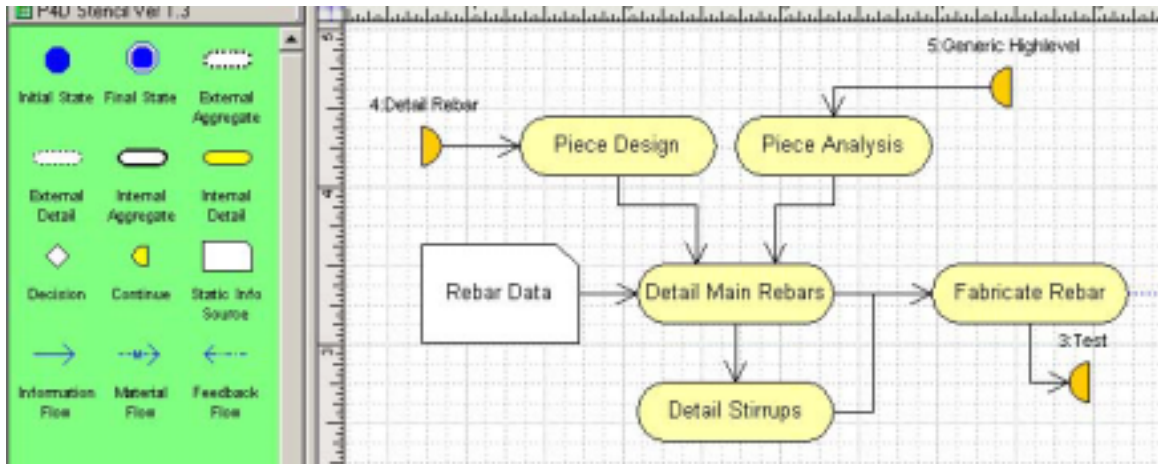priori through consensus among consortium member representatives.

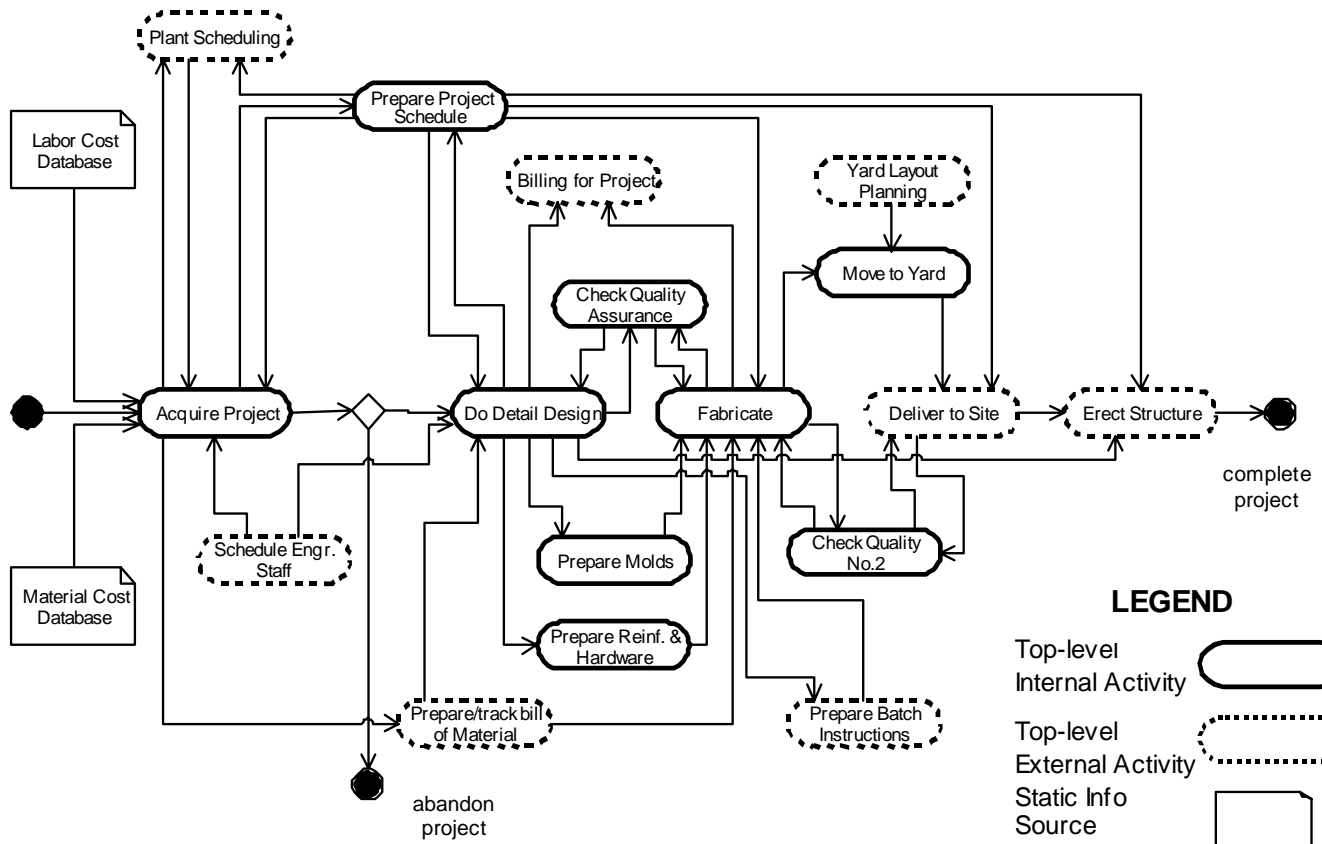Figure 3: Graphic interface of the GT PPM Tool (Lee et al. 2002).

Figure 4: Generic top-level process model

In addition to supporting the diversity of business models within the precast industry and capturing information-rich models, the methodology also provides the following benefits:

- Preparation of the models enables each participating company to understand and strategically plan the changes in their businesses that must accompany re-engineered software and information integration. This encompasses human resources, bidding and cost estimating, engineering design, production, erection, and accounting practices.

- The diverse models produced provide the basis for the perspectives on the precast industry management processes presented in the following sections.

Precast Concrete Industry Process Models

In all, fourteen detailed process models were produced. In most cases, the models represented a process that was initiated with a standard contract bid, and included the full gamut of activities: cost estimating, bidding, contract award, assembly layout design, structural analysis, detailed piece design, production, handling, shipping, erection, scheduling and project control. The modelers view was that of precast designers and producers, which defines the scope of the models. Client activities such as conceptual programming, overall project costing, and life cycle issues such as design for demolition and recycling, do not appear in any of them.

Three models described a design-build process, and so covered the conceptual design phase in greater detail than the more traditional bidding process models. Two models were prepared by precast design consultants and so cover the design phase alone. Each model underwent a number of cycles of review by the research team and improvement by their authors before being approved for inclusion in the analysis and further development work. One model was rejected due to lack of detail, leaving thirteen models to work with. Each company was also asked to prepare a second model, which would reflect the company's business processes as they envisioned them *after* incorporation of the re-engineered software and product data models in their business processes. Three such models have been prepared, and more will be generated in a second round of modeling, in the next phase of this research.

The models ranged in levels of detail, both in terms of the number of detailed activities, and in the extent of the information items used to define each activity. Table 3 indicates the complexity of the models collected. The largest model included 323 detailed activity types and 572 distinct information flow types. The ratio of the number of information flows (n_F) to the number of detailed activities (n_A), which indicates the degree of information dependence between activities, is relatively unvarying from model to model, ranging from 1.56 to 1.89. Figure 5 shows one page of a typical process model.

Table 3: Process Model Statistics

Model Type (1)	Feature (2)	Average (3)	Largest (4)
Design Build Models	n_A	269	323
	n_F	476	572
	n_F / n_A	1.77	1.77
Sub-contract Models	n_A	154	275
	n_F	232	520
	n_F / n_A	1.50	1.89
Design Only	n_A	57	81
	n_F	89	130
	n_F / n_A	1.56	1.60

n_A = Number of Activities; n_F = Number of Information Flows

The primary motive for analyzing the process models was to reveal the foci of information exchange and to explore their detail, in support of specifying new software and a product data model for the precast concrete industry. The three types of analysis described below facilitate examination of the business and engineering practices common in the precast industry. Additional analyses of the information flows in the models, such as their use in direct derivation of a product model from the process model (Eastman et al. 2002), are beyond the scope of this paper.

Level of Detail of Activities and Libraries

All of the models use the generic top-level model as their starting point. Although modelers added additional intermediate layers of aggregate activities, every detailed activity can be traced to one common top-level activity. Using this as a starting point for analysis across companies, a list of middle-level activity groups was compiled for each top-level activity. The level of detail for each activity group, over all the models, was determined using four measures: the total number of detailed activities in each group, the number of models that contained detailed activities of each group, the average number of detailed activities

in each model for each group, and the maximum number of detailed activities in any model for each group. The results (Lee et al. 2002) provide a clear indication of where the information flows are concentrated.

Figure 5: 'Acquire Project' detail page of a typical process model.

Much of the information used in the precast industry is persistent beyond the level of any particular project. Some may be unique within individual companies, while other information – such as that describing design codes, off the shelf hardware, steel sections and reinforcing - is common across a national industry. Although the models have a project focus, sources of information external to any particular project must be modeled. This was done using 'static info source' symbols. The modelers cited 41 such unique repositories.

Analysis Using Information Flows

The detailed information flows captured in the process models provide a view of the complexity of information processing occurring in the detailed activities. The generation, use and change of value(s) of any individual information item can be tracked. Grouping attributes facilitates comparison of the ways in

which information is used across different companies. Models that appear to be identical, through observation of their activities alone, may in fact be quite different in terms of the ways in which information is used within those activities.

In order to expose the practices embedded in the process models, the information items that are common to any select set of models being compared are identified. Next, for each item, the top-level activity in which it is generated in each model is determined by aggregating from detailed- to top-level activities. Then, since top-level activities are common across companies' models, comparisons can be made, as described in Figure 6. When differences are found, examination of the information included in one model but excluded from the other aids interpretation. The full results, with examples of the insights they provide, are reported in Lee et al. (2002).
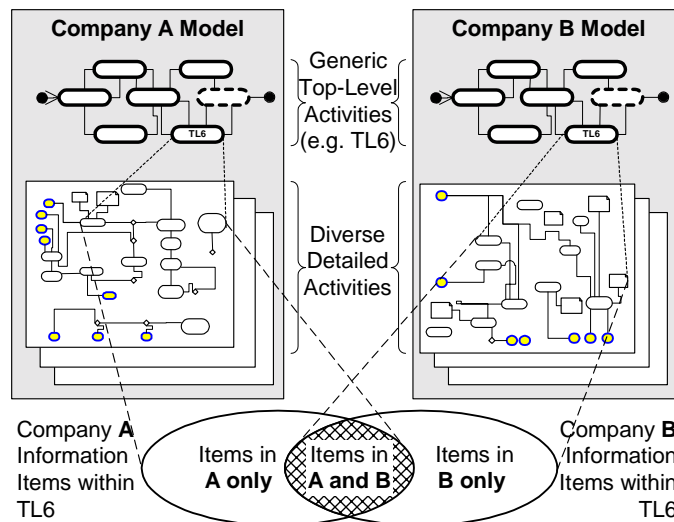

Figure 6: Comparison of information items across common top-level activities.

Design Structure Matrix (DSM) Analysis

Design Structure Matrices (DSM) (Steward 1981) can be extracted automatically from GT PPM process models. During the model development stage, the technique was applied to locate errors or omissions in the models: activities without any input information flow are automatically identified, as are activities that produce neither information nor material product. In completed models, the DSM technique allows identification of iteration loops in the process; an example is shown in Figure 7. In such situations, the

information required for the earlier activity is at first unavailable. Reasonable values must be assumed based on best estimates, thus allowing the process to proceed ('Select Trial Type and Geometry). Once the later activity is performed, more accurate calculated values become available. Process flow can then return to the earlier activity, thus creating the iteration loop. At some point, the calculated values are deemed sufficiently close to the assumed values, and then iteration ceases (this may sometimes occur in the first iteration).
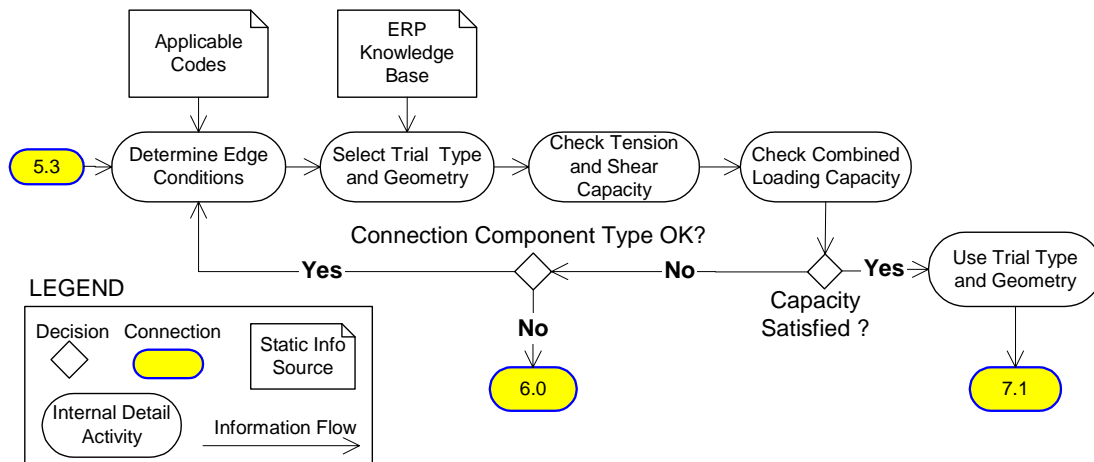
Figure 7: A typical iteration loop in information flow (precast connection design).

The DSM bandwidth represents the greatest number of activity steps over which iteration is performed, i.e. the longest flow of required information from a subsequent project activity to a precedent project activity. The bandwidth is shown in Figure 8.
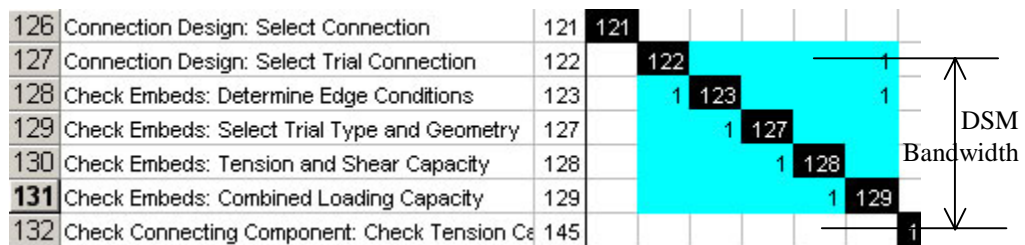

Figure 8: DSM Bandwidth for a typical partitioned DSM

One observation was that in a small number of models, modelers used information flows to impose process flow direction in situations where no material flows existed, which in certain cases resulted in nonsensical results from DSM analysis. Wherever the analysis revealed this, the modelers were advised to use material

flows where appropriate or to release unnecessary information flows. In cases where both material and information were transferred, parallel information and material flow arrows were used. An additional difficulty was that the generic DMS analysis tool used (Tyson et al. 2000) does not allow distinction between material and information precedence. Information precedence is 'soft', in that in the DSM paradigm values can be assumed for unavailable information; material precedence is 'hard', and must be imposed. An improved algorithm appears necessary.

Perspectives on Precast Practice

Previous work on management practices in the precast construction industry is sparse. Warszawski (1982) detailed a methodology for planning production runs for multiple product types on multiple molds. This work also includes the earliest formal definition of an information system for precast production plant. Dawood (1996) described an expert system for integrated bidding and production management. Pheng and Chuan (2001) report the efforts of precast producers to introduce just-in-time delivery to general contractors. The following discussion draws on the analyses described above to provide a perspective on current management practices in the North American precast industry. Although process models alone cannot fully describe the complexities of an individual enterprise (Kirikova 2000), models of the same basic process across numerous enterprises allow high-level comparison of some important issues across the industry.

The comparative analyses expose significant diversity in the companies' processes. Some of the differences are due to differences in building or product type, contract type and existing management software systems (such as ERP- Enterprise Resource Planning). The points in the processes at which the analyses (mainly information flow analysis) revealed changes in the nature of the information used, indicate how the process should be conceptually sub-divided in order to provide re-engineered software that can support each product and contract type. The main process phases are: Conceptual Design, Structure/Assembly Layout, Assembly Design and Analysis, Piece and Connection Detailing, Fabrication, Storage, Delivery and Erection. These, and their sequence, are common across all of the models. Sales and Scheduling activities appear at different points in the process, depending on the contract type. Three contract types appear in the models:

1. **Design-build**, in which the precast producer has full responsibility for conceptual design. Two distinct variations exist: in the first, (a), the contract is signed soon after the start of the project, before conceptual design is complete. This demands accurate cost estimating at a stage where no detailed design information is available. In the second, (b), estimating risk is reduced as the contract is only signed after approval of conceptual design.

2. **Sub-contracting**. Two product types are included here: a) complete building structures, in which the precast producer must perform structural layout, design and analysis, and b) specific building assemblies, such as facades or isolated slab systems, in which layout is dictated by the architect and engineer of record.

3. **Component Supply.** The precast producer is required to perform piece detailing only.

Note that in no case did the precast producer assume the role of general contractor. Close correlation was found between building or product type, and contract type: the more sophisticated the building system to be supplied, the earlier in the process the contractual engagement between the precast company and the owner is confirmed. Complete buildings were provided only by design-build contractual arrangements. Figure 9 shows the correlation of product types with contract types, examples of projects in each group, and indicates the activities performed by the precast company both before and after contract closure.

There are significant discrepancies between models with regard to the amount of detailed design performed prior to award of contract. In all cases, the precast producer must estimate the variety and quantity of pieces that will be required. Some of the companies estimate their jobs in specific cost estimating activities, which have as input only the basic information supplied by the client; others perform comprehensive general arrangement and piece design and analysis activities in order to obtain accurate quantity estimates. No significant difference could be discerned in either the building or contract type to account for this (items 1a and 1b in Figure 9 show this clearly – it occurred in the other contract types as well). It represents different management attitudes to the trade-off between the risks of investment of resources in detailed cost estimating (should the contract not be awarded the investment is lost), versus the risk of bidding a job with cost estimates that are less accurate but less costly to prepare. The issue is of significance in terms of the

overall goal of re-engineering precast concrete software based on integrated 3D models. In such an environment, automated design and detailing will enable a precast producer to perform highly detailed and accurate cost estimates at extremely low cost. This was evidenced in all of the process models that describe companies' future processes: the building assembly layout was fully detailed (using a 3D computer model), and a detailed bill of materials was produced, before the bid and negotiation activities.
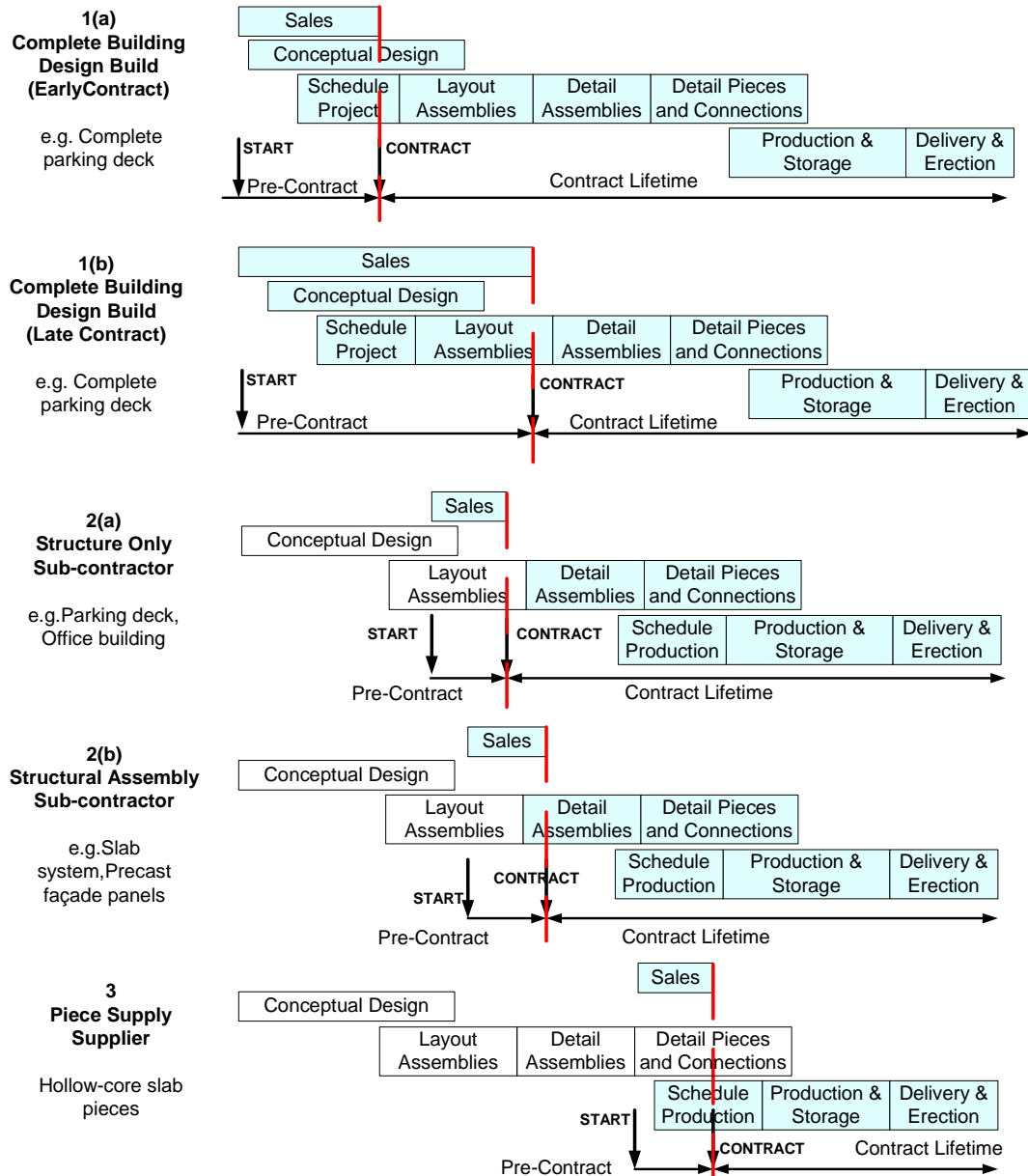

Figure 9. Product type, contract type, example projects, and associated precast company activities (activities performed by the precast producer are shaded).

The practice of outsourcing overflow design work to outside consultants is common (appearing in 5 out of 9 relevant models). Considerable attention was given in the models to scheduling design personnel, in order to determine the need for outsourcing design and drafting work. The implications of outsourcing on integrated software should be considered, including the need for data exchange compatibility and workflow integration. In addition, increased efficiencies in their internal design operations may allow companies to suffice without outsourcing. At present external engineering consultants account for 22% of all computer-aided drafting stations in the industry (PCI 2001).

None of the models detailed energy (thermal) or acoustic analyses, at levels of either building assemblies or individual precast pieces. Given that the knowledge and resources for thermal and acoustic analysis are readily available (PCI 1999), one might assume that these are not of major concern in the majority of precast projects.

Preliminary interference checking to find space conflicts between embeds and reinforcing or prestress cables does not seem to be performed well at the design stage. In most companies' processes, interferences are first identified during placing of the components in the mold. This may result in delays, or even require redesign – Figure 10 describes this process. In general, quality control (QC) activities were included in all of the models, but were closely related to the activities whose output they checked. High-level QC activities were absent, suggesting that companies have adopted quality assurance procedures within the process activities, performed by design and fabrication personnel directly. This is consistent with the spread of total quality management (TQM) procedures and standards, which have reduced the need for distinct QC departments and activities in other manufacturing industries (Hernandez 1993). Material quality checks requiring specialized equipment, such as concrete strength tests, were modeled: these remain the preserve of distinct QC departments.
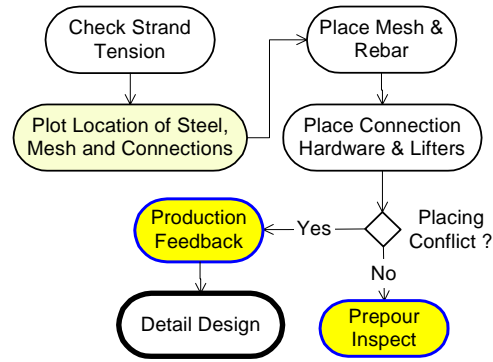
Figure 10. A typical process sequence identifying spatial interference.

Three different approaches to mold design for façade panels were identified. They may be called 'mold-first', 'piece-first', or simultaneous design. In mold-first design, the company offers a limited range of panels dependent on the forms it has available. Piece-first design requires a company to order or adapt forms according to the pieces designed by the project architect. The simultaneous design approach is less common, and more complex: piece designs are adapted to match new or adapted mold designs, in such a way as to minimize the overall number of molds required to produce all of the panels for the building. A typical result of this approach is shown schematically in Figure 11, in which three product shapes can be made from one custom-built mold (Eastman et al. 2001).
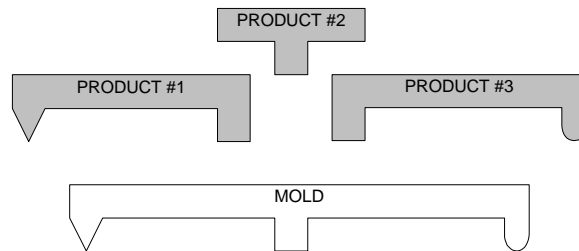

Figure 11: Mold design using a simultaneous approach.

While different production plants concentrate on different products, there is very little diversity between products of the same type across different companies. The information items used to describe the basic precast pieces – such as double-tees, hollow-core planks, columns, beams, façade panels, walls, stairs, etc. - vary only in nuance.

Communication through the entire process is currently heavily paper-based. Many activities depicted in the models are concerned with production of assembly arrangement drawings, piece tickets, bills of material,

etc. These documents serve to communicate information from one actor in the process to another. They are not merely representations of the project data, but actually *contain* the information describing the project as it is carried across the interfaces. Despite the fact that all of the document production activities are computerized, computer *modeling* of project data is rare. A recent survey conducted by the Precast Concrete Institute (PCI 2001) supports this view; it revealed that 96.7% of workstations used for engineering detailing in the 81 producer companies surveyed made no use of 3D modeling. The equivalent figure for the 10 engineering companies surveyed was 89%. In the models describing the future process, incorporating integrated information and 3D modeling, a paradigm shift is apparent. The information describing the project is transferred directly (electronically) from activity to activity, without the need for paper communication. Paper documents must still be produced, but only in order to expose the information to human reviewers.

The number of information exchange interfaces in the processes increases as the number of distinct organizations – different departments within the precast company or external designers and contractors – increases. A second indicator of complexity in the process is provided by the DSM analyses listed in Table 4. Complexity is greatest in the design-build models, although one company's sub-contracting model exhibited very high bandwidth. Reducing interfaces and complexity is a key component in re-engineering the precast process to reduce design lead-time.

Table 4. Process Model DSM Bandwidth Statistics

Model Type (1)	Feature (2)	Average (3)	Largest (4)
Design Build Models	b	39	39
	b / n_A	0.15	0.18
Sub-contract Models	n_A	19	71
	b / n_A	0.12	0.5
Design Only	b	6	8
	b / n_A	0.10	0.10

b = DSM Bandwidth ; n_A = Number of Activities

Despite the diversity in management processes, there is little variation in the types and characteristics of the basic precast piece 'building-blocks' produced by companies across the industry. The information items used to describe precast pieces and the embeds, reinforcement, prestressing, connection hardware, etc.

typically cast into them, are essentially the same for all companies, irrespective of the contract type or management processes.

Conclusions

The GT-PPM has proved to be an effective tool for collecting information rich process models of precast concrete companies. The models produced within the PCSC research project have provided perspectives on some of the current management, engineering and production practices of the North American Precast Concrete industry. While the high level process phases and their sequence are common across all of the companies, significant differences are apparent at the detailed level. Different companies specialize in either design-build, sub-contracting, or component supply, but none acted as general contractors. These differences in contractual arrangements show direct correlation with the type of buildings produced. The degree of detail invested in design for cost estimating before contract closure also varied widely. The approaches to mold design are also quite different, depending on building and product types. Some companies perform engineering design in-house, while others outsource all of their engineering work to consultants. On the other hand, some aspects show little or no variation across companies. The basic precast piece product types are relatively uniform. Communication of engineering data remains almost entirely 2D or paper-based in all of the companies. Quality assurance and control activities in the models indicate adoption of total quality management practices in most companies.

The process modeling activity itself contributed directly to the participating companies in three important ways. Companies were able to examine their practices in fine detail, in many cases leading to re-engineering of their processes. The participants were also exposed to the process models of other companies, with similar effect. Lastly, some companies used their process model to explore the ways in which their business and engineering process could be re-aligned once the integrated software tools planned by the PCSC become available. This has allowed them to formulate strategy for identifying and preparing the necessary organizational and personnel changes.

Many factors influence the market share of precast concrete, which at 1.2% is significantly lower than that in other industrialized countries. Currently, there is little or no use of parametric 3D modeling and data

integration in the North American industry. Thus there is significant motivation and potential for improvement in the precast design and production process by application of information integration technologies – specifically through re-engineering of the software used in the industry, to support integrated 3D based modeling of the information describing precast projects, together with development of a Precast Concrete Product Model (PCPM).

Development of the re-engineered software and precast product model, with the goal of integrating the information flows throughout the precast process, is ongoing. Beyond their contribution to the current work, the extensive models reported here may also provide a control set for future investigation of the impact of information integration on precast concrete companies in the areas of construction cost estimating, engineering design, production, and human resources.

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