A Case Study of IFC and CIS/2 Support for Steel Supply Chain Processes

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Summary
The evolution of data exchange and integration standards within the Architectural, Engineering and Construction industry is gradually making the long-held vision of computer-integrated-construction a reality. The Industry Foundations Classes and CIMSteel Integration Standards are two such standards that have seen remarkable successes over the past few years. Despite successes, these standards support the exchange of product data more than they do process data, especially those processes that are loosely coupled with product models. This paper reports on on-going research to evaluate the adequacy of the IFC and CIS/2 standards to support process modeling in the steel supply chain. Some initial recommendations are made regarding enhancements to the data standards to better support processes.

1 Introduction
The Architectural, Engineering and Construction (AEC) industry has for the most part of the last two millennia depended on paper-based drawings and documents for project execution. The last two decades has witnessed tremendous movement of the AEC industry towards the digital paradigm and most importantly, recent years have seen the maturation of data integration models. The Industry Foundation Classes (IFC) and CIMSteel Integration Standards (CIS/2) are two such data exchange standards that have been widely supported and implemented. The evolution of such models makes the possible realization of long held visions for computer-integrated-construction (CIC) via shared integrated data models and information management.

Despite its wide base of support, use and implementation, data standards are currently considerably more mature for product modeling than for process modeling (Froese et al. 1999; Staub-French and Fischer 2000). A construction product model provides geometric and topological information of the product of construction, while a construction process model provides temporal and resource information. Through research, product modeling has been well supported, tested and implemented. However, relatively few efforts have been made to evaluate existing standards with regard to their support for processes, particularly processes that are loosely coupled to product models. Such processes include scheduling, resource management, and procurement.

This paper complements several existing efforts that are focused on product modeling and processes tightly linked to product models such as automation of erection activities and estimating. The two primary objectives of this paper are:

1. To document and analyze procurement and scheduling processes within the steel fabrication and erection supply chain, and
2. To verify how these processes are supported by IFC and CIS/2 data standards.

An introduction to the steel construction supply chain with respect to the above-mentioned scope is outlined. This is followed by a brief discussion of the advantages and limitations of data exchange and integration standards within the AEC industry. CIS/2 and IFC each have their different scopes, architectures and mode of operation that provide different advantages and disadvantages when considering their support for existing processes. To make an effective critique, data on current in-use processes is presented and compared with the IFC and CIS/2 standards. Some recommendations are presented to extend the IFC 2.x and CIS/2 standards based on the critique.

2 The Steel Construction Supply Chain and Standards Implementation

Figure 1 shows the configuration of the steel supply chain, centered around a fabricator that is the principal coordinator for detailed design and delivery of steel to a job site. For the purposes of this paper, the research focuses on just the fabricator and erector, however the overall scope of the research is inclusive of many actors.

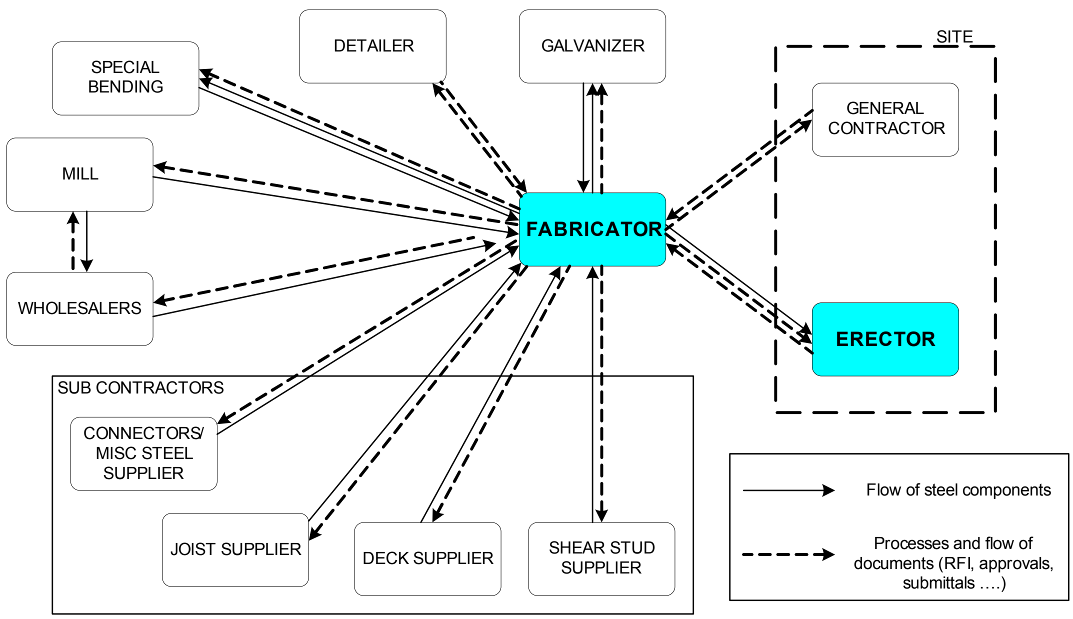

Figure 1: Steel fabrication and erection supply chain

The number of actors in the steel supply chain is large, suggesting that data standards for information exchange could provide a valuable service to the industry. CIS/2 has been implemented by several software vendors (e.g., commercial applications that support CIS/2 translators include Xsteel™, Fabtrol™, SDS/2™ and Structural Triforma™). The American Institute for Steel Construction has endorsed CIS/2 and is actively promoting further expansion (AISC, 2004). New developments such as NIST's VRML viewer enables the real time navigation of steel project drawings and data in a three-dimensional environment (Lipman and Reed 2003). The industry as a whole has been very receptive of these developments and has incorporated them in active projects (AISC 2004). As active users and supporters of product model standards, the steel construction supply chain provides a fertile test bed for this research.

3 Data exchange and integration standards the AEC industry

This section briefly reviews the structure of the IFC and CIS/2 standards. These and related data standards are considerably developed for product modeling, while the capture, analysis and modeling of the process by which products are made has been relegated to the background (Froese 1995). Froese (1995, 1996) reviews a separate stream of process modeling research, and suggests an integrated AEC core process model. Alshawi et al. (1999) note that although there has been governmental, industrial and international support for some process models, most of them have been developed within academia and the integrity and reliability of these models have not yet been tested. A goal of this research is to document processes in detail and test the ability of the IFC 2.x and CIS/2 standards to support process data exchange. As such, this research also supports evaluation of process modeling methods.

3.1 Industry Foundation Classes IFC

The Industry Foundation Classes (IFC) is perhaps the largest and most ambitious effort that is being undertaken to develop an integrated building model (Eastman 1999) with the hope of achieving the goal of Computer Integrated Construction (CIC).

The IFC model architecture (IAI 2000) is built up of data model schemata organized in four main layers namely, resource layer, core layer, interoperability layer and domain layer.

- The lowest layer contains the resource classes that classes used by classes in the upper layers. These classes are general, low level, domain independent and even not AEC-specific such as date and time.
- The core layer which comprises the kernel and core extensions (control, product and process extensions). The kernel provides the basic abstract part within the IFC architecture. Similar to the resource layer the concepts in the kernel are general and non-AEC-specific such as object, property and relationship but they are required for all other higher level models. The purpose of the core extensions is to serve as the first line of specialization of the kernel objects towards AEC specific constructs. For instance the core process extension provides information that supports the concept of process in the context of AEC and the core product extension helps to define the properties of the product (building component).
- There are some objects that are shared by multiple domains. Such objects are captured by the interoperability layer. Major building elements like wall, beam, column, slab, roof and stair are not unique to any one particular domain and thus are captured by the "shared building elements" data model.
- The final and topmost layer is the domain layer. As a result of successive refinements, the model at this layer provides domain specific support. The models that are currently contained in the domain layer of IFC2.x are HVAC, electrical, architecture, construction management and facilities management.

3.2 CIMsteel Integration Standards Release 2 (CIS/2)

CIMsteel Integration Standards, an outcome of the Eureka EU120 CIMsteel Project, is a set of formal computing specifications that allows software vendors to make their engineering applications compatible. The CIS standards are based upon a formal product model known as Logical Product Model (LPM) which defines a logical structure for data in terms of entities, attributes and relationships between these entities (Crowley and Watson 2000a).

Within CIS/2 there are three different views in which a structure can be represented. These are the *analysis*, *design assemblies* and *manufacturing assemblies* that map onto the viewpoints of the analyst, designer and manufacturer respectively. With respect to implementation, CIS/2 is divided into 17 major subject areas. These subject areas which include loading, geometry and structural response are all product-centered except for process definition and data management subject areas which deal with process modeling. As stated in the standards, CIS/2 provides a limited coverage for contractual organization, project planning, and project scheduling and costing (Crowley and Watson 2000a).

4 Data Collection

This research uses a case based approach to develop detailed descriptions of scheduling and procurement processes used by steel fabricators and steel erection contractors. The aim is to capture processes used in the day-to-day running of steel fabrication and erection businesses.

Within a case based paradigm, a frequent approach is to utilize standard icons in a simple flow chart to depict processes and their dependencies. The weakness of this method is that is assumes these processes are known in advance (Verner 2004). During our research we found out that the firms do not know their end-to-end processes accurately or in detail, supporting Verner's observations. Furthermore, this approach is unable to capture all the data and constraints associated with a process in order to build an effective and valid model (Abeysinghe and Urand 1999, Verner 2004). It takes more than a standard flow chart to elicit this kind of information from domain experts. As a result the IDEF3 "Process Description Capture Method", a modeling concept that provides an excellent mechanism for effective data collection and documentation was adopted. IDEF3 captures temporal, precedence and causality relations between processes and events as well as model decisions in a form that is natural to domain experts who may be non-technical with respect to the concept of modeling (Mayer et al. 1995). We note that the IDEF3 method is consistent with the process modeling approaches described by Froese (1996).

The flow chart shown in Figure 2 (adapted from the IDEF3 structured methods (Mayer et al 1995) and slightly modified), served as a guide for the data collection methodology. A specific benefit of IDEF3 is that it provides a structured method for logging all the data and documentation associated with a process. Collection of supporting documents, together with the detailed structure of the IDEF3 process representation, provides for checks of the logical coherence, validity and overall consistency of the (Abeysinghe and Urand 1999, Eastman et al. 2002; Lee, et al. 2002, Phalp et al. 1998).

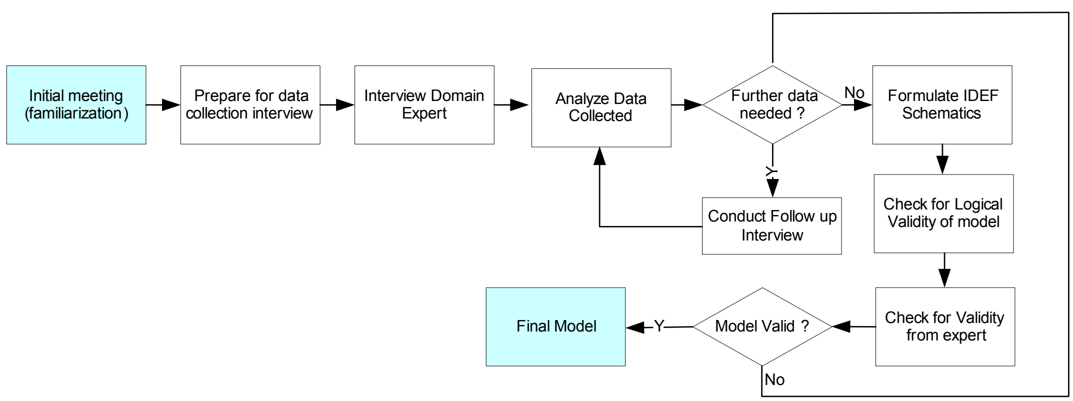

Figure 2 Data collection methodology

An initial visit enabled the research team to familiarize themselves with business processes in the participating steel fabrication and erection firms. During this visit a high level process model as shown in Figure 3 was developed as well as the firm specific steel supply chain as shown in Figure 1 (particular configuration and names of suppliers and subcontractors). These models were iteratively decomposed and refined into detailed activities (Figure 4), each time checking the validity or otherwise with the domain experts. Each unit of behaviors, that is the activity node, is supported by additional elaboration sheets (Figure 5) that list actors, the documents, tools, methods, input, outputs, facts and constraints associated with the process. Temporal constraints are visible from the process schematics and hence are not included in the elaboration sheet. During the process of data collection, emphasis was placed on how these processes are currently executed on the site or shop rather than thinking about how they could be improved.

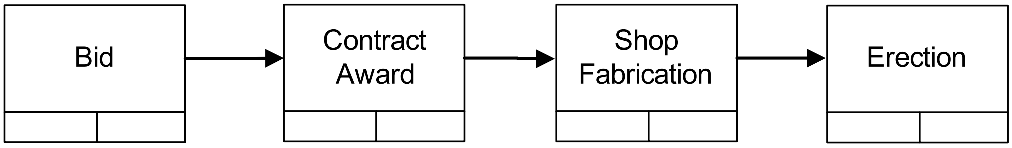

Figure 3: High level IDEF3 process schematic for fabrication and erection

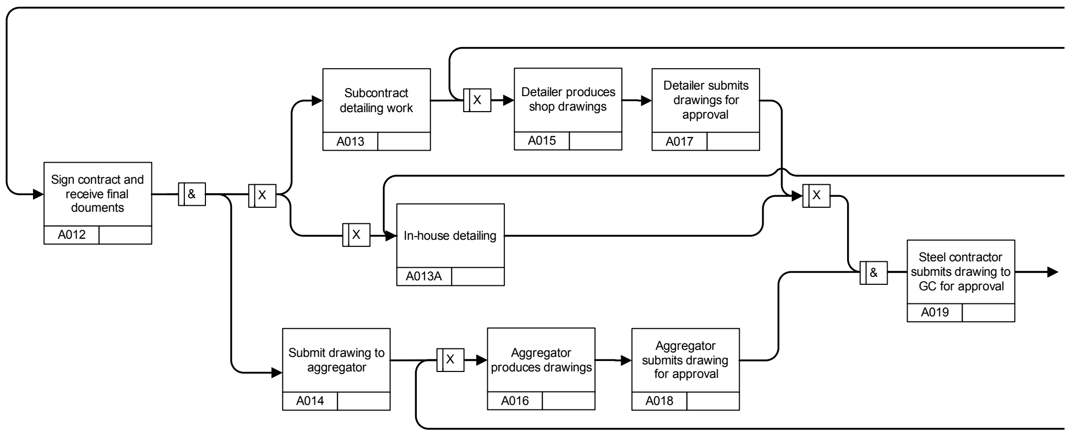

Figure 4: Partial IDEF3 Second level decomposition

Project		Date: 2/20/04
UOB No. A015	Detailer produces drawing.	
Tools	CAD package (AutoCAD, SDS)	
		See Document Log # details
Documents	RFI and response to RFI	DL# 006
	Shop details	DL# 017
	Erection drawing	DL# 018
	Anchor bolt drawings	DL# 019
	Bill of Materials	DL# 010
Actors	Fabricator's Project manager	
	Subcontracted detailers	
Facts		
Constraints		
Description	Detailer starts working on drawings. Any clarification are resolve through RFIs	

Figure 5: Sample Elaboration Sheet

4.1 Critique of IFC and CIS/2 standards

As discussed above, the IFC 2.x and CIS/2 standards have separate ways of representing processes, IFC by data models organized in layers and CIS/2 in logical domain models. To enable valid comparison, the process maps generated in IDEF3 were used to develop a base inducted ontology of relevant process modeling concepts (O'Brien et al 2003). This ontology was then compared to both the IFC and CIS specifications. Since IFC and CIS are very large models with a great number of different functionalities, the process comparison and critiquing of the existing standards was organized in small blocks. For each of the nodes (unit of behavior) in the IDEF3 model that is within the scope of the research, the entities, actors, controls, methods, constraints, input and outputs were analyzed to determine how they are supported by the IFC and CIS/2 standards. Below, we discuss critiques and extensions around process models for fabricator and erector material procurement and scheduling of approval of drawings.

4.1.1 Fabricator and erector material procurement

In an ideal situation, the fabricator should place an order to the steel mill once the fabricator is awarded the contract. This is because production and delivery of steel by the mills has a long lead time – normally eight to ten weeks for participating firms in our case studies. However immediate procurement is not always feasible as many factors such as drawing approval, storage space, and capital come to play in the material procurement process. From the case studies it was observed that steel warehouses (distribution centers) had smaller lead times (usually three to five days) but at a higher cost of steel. Similar constraints are encountered when fabricated steel needs to be shipped to the jobsite for erection. In this situation additional constraints such as maximum dimensions and maximum transport weight of fabricated components must be taken into consideration. Furthermore, on some projects sites, storage space is limited and often the concept of just-in-time is employed, with components arriving on site when needed for erection.

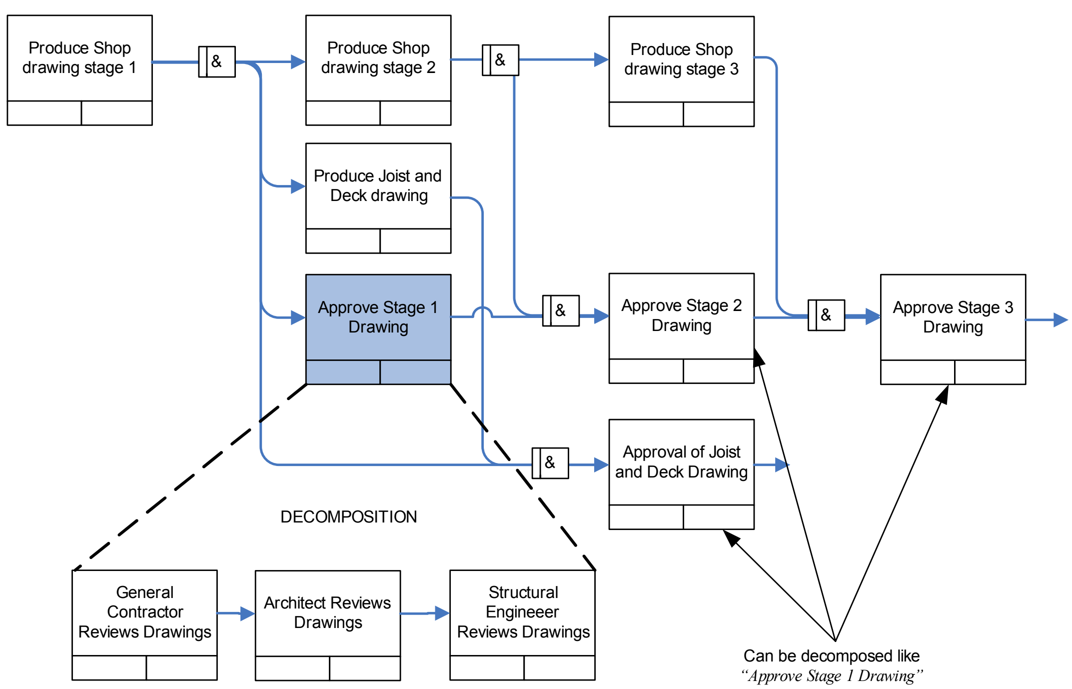

Figure 6: Detailed view of the stage-type drawing approval method

4.1.2 Scheduling of approval of drawings

Development and approval of drawings is a tedious but important component of the fabrication process that enables the project to be properly fabricated and assembled smoothly during the erection process (Mrozowski et al. 1999). These drawings include anchor bolt details, shop drawings, and erection drawings. From the case studies it was noted that the time for approval was between two and three weeks and for fast track projects it was efficient to produce the drawing in batches corresponding to stages in the project and then submit them for approval (Figure 6). For contracts based on the AISC specifications the accepted approval period is two weeks.

4.1.3 Process model support by IFC 2.x and CIS/2

With regard to the documented processes of material procurement and drawing approval, the IFC standards are generally adequate to allow process modeling and representation. For instance, although there is no steel-specific representation for documentation in the above-mentioned processes, the IFC has provisions such as IfcCMDocPackage within the IfcConstructionMgmtDomain that handles such documents. In addition, the IFC has an entity *ifcScheduleTimeControl* within the *ifcProcessExtension* model of the of the core layer that takes care of temporal scheduling constraints such as early delivery dates, late delivery dates, critical activities and more. On the other hand it was observed that the CIS/2 standards had quite a number of missing entities and attributes within the *process definition* subject area to enable it capture the data obtained from the case study. A typical example illustrated in Figure 7, shows part of a LPM/5-EXPRESS-G model for *procure* of "process definition (subject area 16)". This handles material procurement in the CIS/2 standards. The attributes compared with data collected from the case studies found time constraints items such a such as e*arly delivery*, *late delivery dates* and *activity critical* missing.

It must be emphasized that care was taken to account for all related entities as some processes span across various subject areas for CIS/2 and layers for IFC 2.x. A summary of the results for the procurement and approval processes is shown in Figures 8-10. These figures list the items that were obtained from case study data, how they are supported by IFC 2x and CIS/2 in their current state, and finally indicate and need for an extension. A typical example of how proposed extension embedded in the existing CIS/2 standards might look like is illustrated in Figure 11. A summary of all the proposed extensions to CIS/2 and IFC 2.x are shown in Figures 12 and 13 respectively.

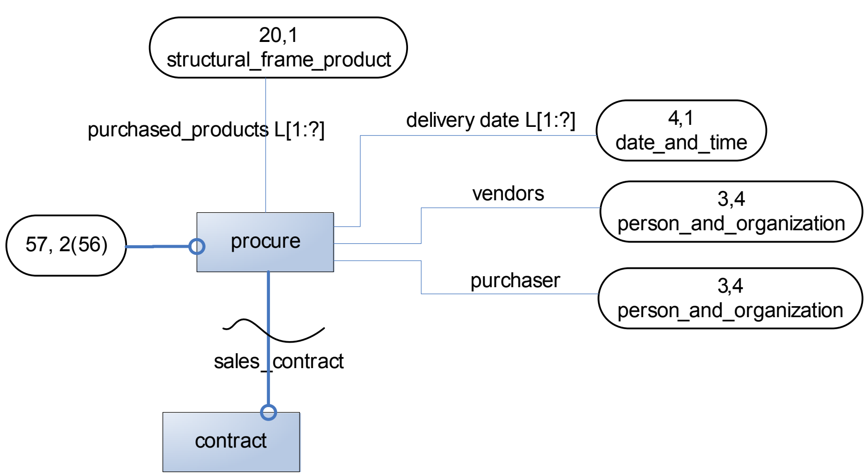

Figure 7: Section of the LPM/5-EXPRESS-G CIS/2 diagram for "procure"

Terms revealed in case study	Existing IFC 2x support	Recommendations needed for IFC?	Existing CIS/2 support	Recommendations needed for CIS/2?
Place order for steel at mill	IfcTask	No	procure	No
Fabricator	ifcActorSelect	No	purchaser	No
Mills / wholesale	ifcActorSelect	No	vendors	No
Specification	ifcCMDocPackage	No	document	No
Cut list	ifcCMDocPackage	No	document	No
Steel Material	ifcProduct	No	purchased_product	No
Minimum tonnage to purchase	IfcConstraint	No	--	Yes
Delivery date	IfcDateAndTime	No	delivery_date	No
Other time constraints (lead time, earliest delivery, etc)	IfcScheduleTimeControl	No	---	Yes
Delivery bill	ifcCMDocPackage	No	document	No

Figure 8: Material Procurement (from mills or wholesalers)

Terms revealed in case study	Existing IFC 2x support	Recommendations needed for IFC?	Existing CIS/2 support	Recommendations needed for CIS/2?
Transport to site	IfcTask	No	dispatch	No
Fabricator	ifcActorSelect	No	Person_and_organization	No
Erector	ifcActorSelect	No	Person_and_organization	No
Fabricator address	IfcAddress	No	dispatch_address	No
Site address	IfcAddress	No	delivery_address	No
Date sent	IfcDateAndTime	No	dispatch_date	No
Date of arrival on site	IfcDateAndTime	No	delivery_date	No
Other time constraints (lead time, earliest delivery)	IfcScheduleTimeControl	No	--	Yes
Fabricated steel component	ifcProduct	No	transported_product	No
Storage available on site or JIT for erection	ifcConstraint	No	--	Yes
Dimension constraint (for transportation)	ifcConstraint	No	--	Yes

Figure 9: Transporting fabricated materials to erector on site

Terms revealed in case study	Existing IFC 2x support	Recommendations needed for IFC?	Existing CIS/2 support	Recommendations needed for CIS/2?
Drawing to be approved	ifcCMDocPackage	No	document	No
Approval process	IfcApproval	No	approval	No
Approving agent	AuthorizingAgent	No	person_and_organization	No
Submitted by	IfcActorSelect	No	person_and_organization	No
Submitted to	IfcActorSelect	No	person_and_organization	No
Date submitted	IfcDateTimeSelect	No	calendar_date	No
Date requested for approval	RequestedDate	No	calendar_date	No
Agreed period for approval	--	Yes	--	Yes
Approval date	IfcDateTimeSelect	No	calendar_date	No
Approval status	IfcApprovalStatusEnum	No	approval_status	No

Figure 10: Drawing approval process

```
ENTITY procure;
SUBTYPE OF (structural_frame_process)
    vendors              :  person_and_organization;
    purchaser            :  person_and_organization;
    purchased_product    :  LIST[1:?] OF structural_frame_product;
    sales_contract       :  contract;
    delivery_dates       : LIST[1:?] OF calendar_date;
    actual_del_date      :  calendar_date
    early_del_date       :  calendar_date
    late_del_date        :  calendar_date
    is_critical          :  boolean
INVERSE
    prices  :  SET[1:?] OF structural_frame_item_priced FOR priced_item;
WHERE
      ……..
END_ENTITY;
```

Figure 11: Extension to CIS/2 (proposed extensions shown in bold face)

Extensions to ***procure***

actual_del_date	:	calendar_date	'actual delivery date
early_del_date	:	calendar_date	'early delivery date
late_del_date	:	calendar_date	'late delivery date
is_critical:		boolean	'is it a critical activity

Extensions to ***dispatch***

actual_del_date	:	calendar_date	'actual delivery date
early_del_date	:	calendar_date	'early delivery date
late_del_date	:	calendar_date	'late delivery date
is_critical	:	boolean	'is it a critical activity
Dim_constraint	:	area_unit	'area allowed to be transported
JIT_constraint	:	boolean	'just-in-time for erection

Extensions to ***approval***

agreed_period	:	time_unit	'agreed contract approval period

Figure 12: Summary of extension to CIS/2

Extensions to ***ifcApproval***

agreed_period	:	ifcDataAndTime	'agreed contract approval date

Figure 13: Summary of extension to IFC

5 Conclusions and recommendations for future work

This paper reports on on-going research to evaluate IFC and CIS/2 support for steel supply chain processes. The methodology through which current practices in steel fabrication and erection was captured was outlined. Based on the case research for procurement and approval process, extensions were proposed to both CIS/2 and IFC 2.x. In general, the IFC standards were found to be more supportive of the processes than are the CIS/2 standards.

To-date, two fabricators and erectors have been studied. Our on-going work seeks more case studies to generalize and expand the results. However, there are limitations with an inductive, case based approach. Thus far in this study, the logic and validity of the process model have been manually checked, a process that can be very tedious and error-prone. Tools and concepts such as enactment models (Phalp et al. 1998; Abeysinghe and Urand 1999), and the Georgia Tech Process to Product Modeling (GT PPM) software (Eastman et al. 2002; Lee, et al. 2002) that automatically checks syntax, logical coherence and consistency are actively being evaluated by the research team. Such tools, incorporated into the methodology, will help speed assessment of the induced ontology and possibly may be extended to partially automate comparison with established standards.

6 Acknowledgements

This work was performed under the sponsorship of the U.S. Department of Commerce, National Institute of Standards and Technology. The authors also wish to thank the firms participating in this research.

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