Supply Chain Modeling for BIM-oriented Construction Schedule Management: CODP-based Classification Approach

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Abstract
Providing accurate, complete and real-time supply and logistics information for construction schedule control is a significant issue in construction management. This paper aims to design a holistic control model for BIM-oriented CSC (Construction Supply Chain). First, this paper analyzes the information requirement of different supply nodes and presents the strategies of lead time management influenced by uncertainty based on CODP (Customer Order Decoupling Point) classification thinking. In the next stage of the study, efforts are made to integrate BIM models into CSC according to CODP-based rule and attention level setting. The approach of BIM-oriented CSC modeling focuses on supply information integration with IFC model as well as the information exchange process among key CSC vertices. It is believed that the approach applied in CSC modeling can help elevate construction schedule controlling, supply lead time planning and BIM model development from the operational level to strategic level.

Keywords: supply chain, BIM, modeling, construction schedule, CODP

1 Introduction
Compared with the manufacturing industry, low productivity, a lag in technical innovation and the lack of management strength have become more conspicuous in the Architecture, Engineering, Construction and Facilities Management (AEC/FM) industry and have been a focus of research in recent years. From the technical perspective, Information and Communication Technology (ICT) has been highlighted as a key driver for innovation and competitiveness in the construction sector (Chopra & Meindl, 2007; Mierop, 2014). It has advantages especially in prevailing BIM (Building Information Modeling) projects. Supply Chain (SC) management has been emphasized in the construction field, which can improve the performance of construction and greatly reduce waste (Alarcón, 1997; Love et al., 2004; Azambuja & O´Brien, 2009). As for CSC management, BIM is expected to promote real-time decision making for better collaboration and coordination in the vertically integrated network structure through a centralized parametric and visual environment. However, the utilization extent of BIM remains low in achieving SC integration. To significantly enhance the capability of CSC in BIM-oriented projects, improving the information availability and flow efficiency is one of the key challenges.

2 Related works
Modeling is a classic approach to understanding complex problems that can be achieved diagrammatically to visualize concepts, and mathematically to analyze attributes of concepts. The nature of the supply chain provides an appropriate environment to conduct the modeling method

(Power, 2005; Pereira, 2009). Modeling the information flow within a particular system or process can lead to a greater understanding of that process (Austin et al., 1996) and these models can then be applied to help avoid the careless processing of incomplete or inaccurate information (Kraol, 1983). Power (2005) focused on information flows for supply chain integration and implementation from a strategic perspective with some cases by demonstrating the focus on the manufacturing phase. Pereira (2009) reviewed the current issues and trends in the IT-enabled supply chain management strategy using examples from manufacturing and logistics case studies. It suggested to use IT to make SC more robust and resilient. Helo and Szekely (2005) examined the benefits of supply chain management that can be achieved through logistics information systems and demonstrated a software classification.

Even though these researches highlight the importance of information sharing in supply chain management, there seems to be a gap in the literature discussing the SC information modeling in the construction field from the operational level to the strategic level. Meanwhile, with the requirement of underlying research in BIM based construction management on interoperability and data integration, CSC modeling can be appropriate and efficient, but remains rarely discussed. By examining the area of information flow in CSC holistically, this paper aims to provide a better understanding of the current research gap as well as be an inspiration for further efficient CSC modeling research.

3 Problem definition

Recent years, simulation approaches have been increasingly applied to support construction projects for different goals of management. With the explicit logic structure and significant influence of construction management, scheduling has taken on an important position in modeling and simulation research. Efficient schedule simulation depends highly on the availability of accurate, on-time and reliable logistics data, but such data is fragmentary, incomplete and discontinuous in practice to some extent. Some researches made efforts to improve the current treatment of uncertain actual logistics data with fuzzy theory and statistical methods (Ponz-Tienda et al 2012; König et al, 2012; Bakry, 2013; Scheffer et al, 2014). They provide solutions to evaluate the logistics data associated with different degrees of uncertainties and further make the schedule reactive or intelligent, which is illustrated in Figure 1 as the Operational Solution.

The other possible solution is to trace the source of required logistics data, through modeling and simulation of the supply chain, to provide more complete logistics information and improve data exchange within supply and construction processes. This paper will focus on the Strategic Solution as shown in the Figure 1:

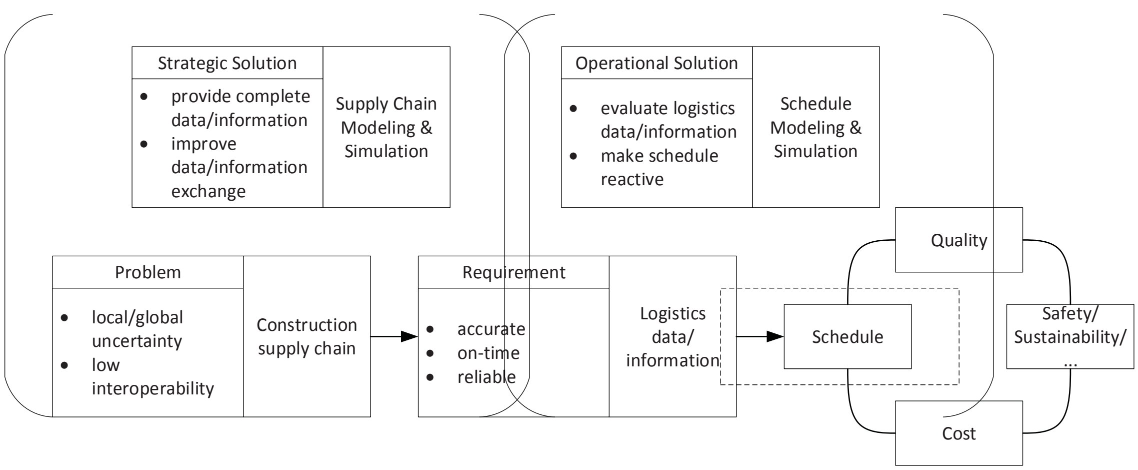

Figure 1 Focus of the research problem

Thus, SC modeling has been emphasized in the construction field, which can improve the performance of construction and largely contribute to avoiding the delay. BIM is expected to promote real-time decision making for better collaboration and coordination. However, how to apply CSC theory to promote both the BIM model itself as well as the supply business activity and finally to achieve the goal of schedule controlling in BIM projects is the most essential problem in this paper.

4 Methodology

This paper describes the initial work for a holistic control model for BIM-oriented CSC schedule management. The approach will be emphasized by: 1) modeling object identification according to the CSC organizational graph structure; 2) a CODP-based supply member definition and information demand analysis; 3) rules setting and process modeling associated with BIM models; 4) schedule control and an attention strategy discussion.

In this paper, modeling objects are to be identified through a top-down logic, which involves CSC structural analysis, BIM-oriented CSC definitions and calculating the information radius of SC graphs. After distinguishing the most tightly involved suppliers in BIM-oriented CSC organizational graph, it is significant to define them and draw out their information need, which is mainly based on the CODP concept in this research. CODP-based classification of supply members would efficiently contribute to rules setting and process transformation associated with IFC models. Applying SC related theory into BIM-oriented CSC is to achieve the goal of providing more complete, accurate and on-time information, which the construction schedule management needs.

5 Theoretical framework of BIM-oriented CSC modeling

5.1 BIM-oriented CSC modeling object identification

The conceptual structure of construction project SC has been already discussed by O'Brien, et al. (2002). They defined main participants such as owners, designers, GC (general contractors), CM (construction managers), subcontractors and multiple types of suppliers, meanwhile the production processes both on-site and off-site were reasonably emphasized. Considering the hierarchy of suppliers is basically one of the main tasks in the manufacturing supply chain, which is necessary to be involved in the CSC structure. In this paper, the conceptual view of a typical construction project SC presented by Azambuja and O'Brien (2009) is adopted, which is shown in Figure 2:

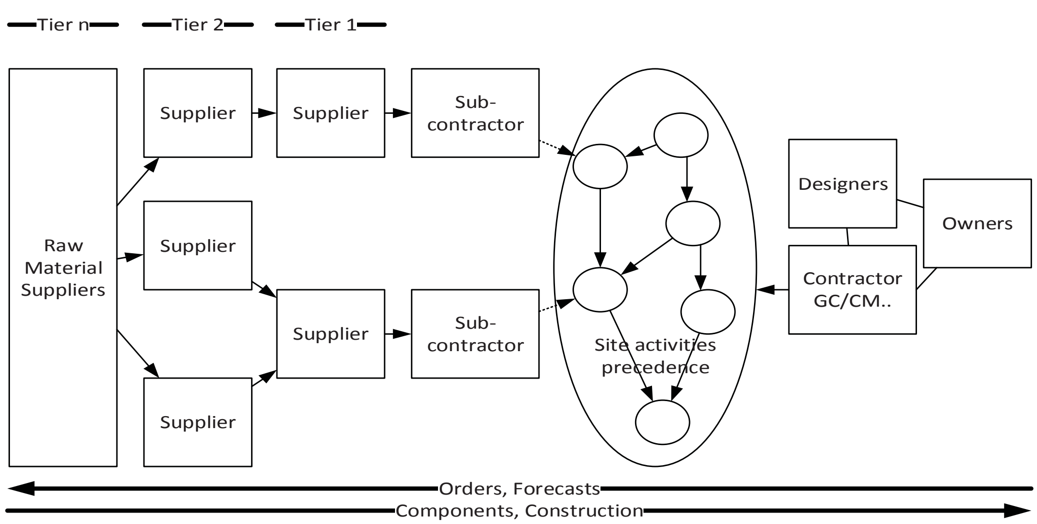

Figure 2 Conceptual view of the construction project supply chain

The information format of most BIM projects is based on Industry Foundation Classes (IFC). BIM becomes a driving force in bridging the stage of design and construction and it consequently changes the structure of a CSC within the range of a project, shown as Figure 3.

In general BIM construction projects, owners, designers, GC, CM, and sub-contractors are reorganized as main participants, while suppliers stand outside. BIM-oriented CSC aims to provide information access to integrate suppliers and contribute to both construction schedule controlling and supply business demand achievement.

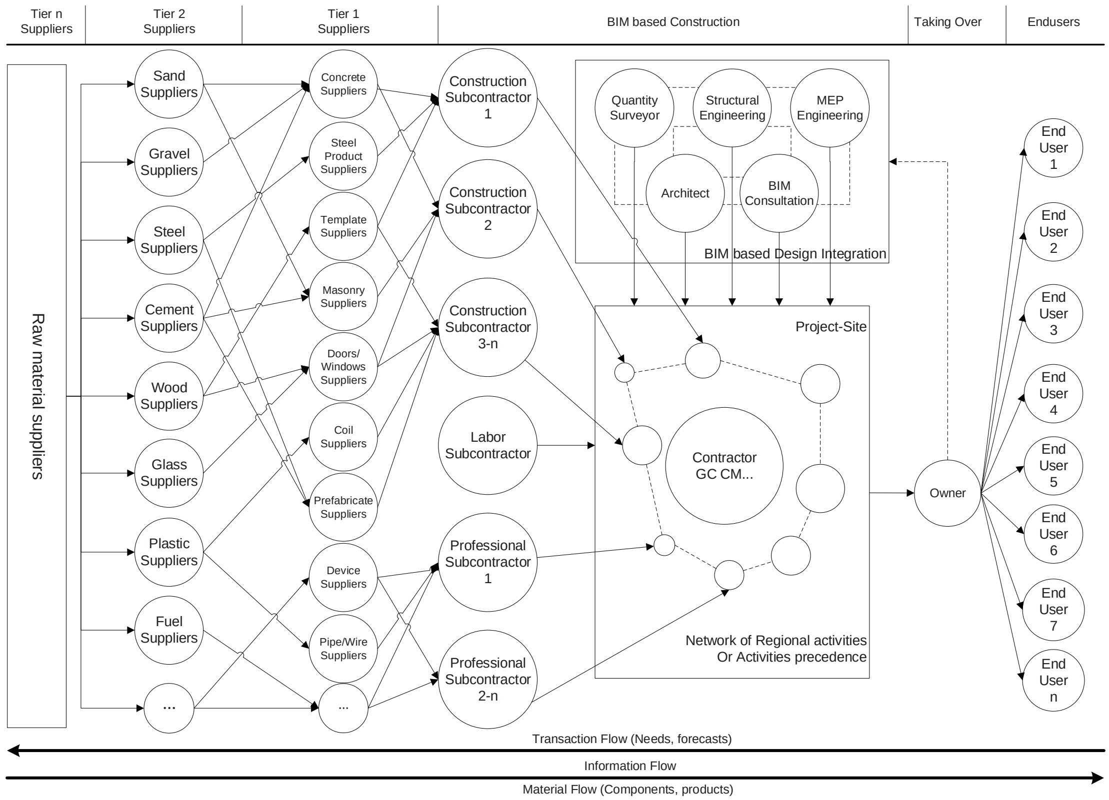

Figure 3 Conceptual view of typical BIM project CSC

In order to get a better understanding of and identify the modeling objects, an organizational analysis is necessary for the BIM-oriented CSC. The basic SC organizational structure could be appropriately recognized as an undirected and connected graph $G(V, E) \in g_{UC}$. In the $G(V, E)$, $d(u, v)$ denotes the shortest distance between $u \in V$ and $v \in V$ where d is a metric. The quantity $\sigma(v) = \max_{u \in V} d(u, v)$ is called the eccentricity of v. $\rho(G) = \max_{v \in V} \sigma(v)$ and $r(G) = \min_{v \in V} \sigma(v)$ is called the diameter and the radius of G respectively. According to previous works of Graph Theory about structural information (Dehmer, 2008), $r(G)$ is suitable to show the local information distance within an un-weighted graph, which is also suitable to figure out the information distance between different participants in the basic SC organizational graph.

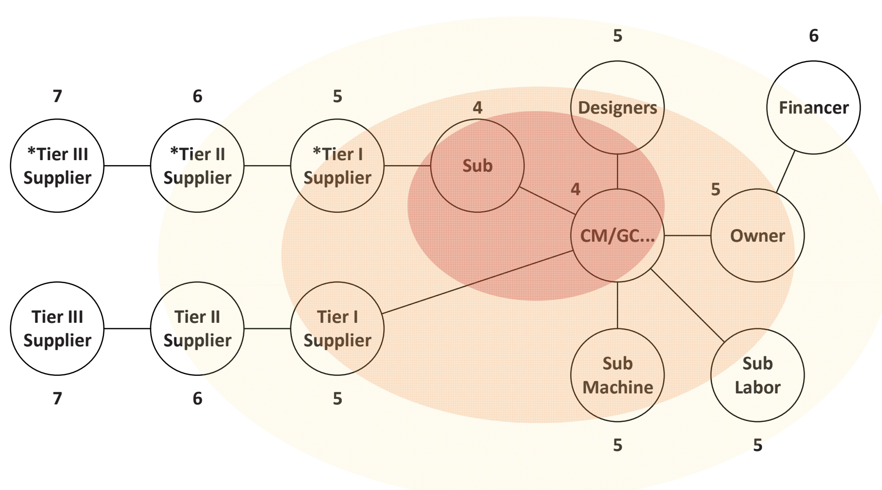

Figure 4 Conceptual organizational radius of CSC

According to the conceptual organizational distance *r(G)*, the most closely related vertices are worked out, shown in Figure 4. As the most significant role on site, the contractor or construction manager takes the core position in a supply chain. Meanwhile, Tier I suppliers of GC and *Tier I suppliers of subcontractors, which hold the main logistic information channel, should be paid more attention. Taking account of the information distance, the BIM-oriented CSC model discussed in this paper consists of the following nodes, with value of $r(G) \in [4, 5]$: GC, subcontractors, designers, owners, Tier I suppliers of GC, *Tier I suppliers of subcontractors.

5.2 CODP-based supply member definition and information demand analysis

The characteristics of four general types of construction products: ETO, MTO, ATO, and MTS have been described and discussed by Wortmann (1992) and Elfving (2013). In the upstream location of a CODP, there are engineered-to-order (ETO), followed by made-to-order (MTO), and then assembled -to-order (ATO), finally made-to-stock (MTS) products, as shown in Table 1:

Table 1 Types of Product according to CODP

CODP	Product Example	Lead Time	Stock
ETO	Power distribution equipment, Preassembled rebar components	long	no
MTO	cast-in-place concrete, prefabricated panels	long/short	no
ATO	doors, windows	short	yes
MTS	consumables such as bricks, bolts	short	yes

From a general management perspective, Wortmann (1992) has already summarized management problems and information modeling demands regarding the supply type. Information requirements are quite different among the types, listed in Table 2:

Table 2 Information need according to supplier members of different product

Focus	ETO	MTO	ATO	MTS
Uncertainty	Specifications	Production process	Mix of orders	Product
Management	Project management	Subcontracting, Shop floor control	Master production scheduling and order contracts	Stock control
Information Model Support	Product engineering	Manufacturing engineering	Material supply and order entry	Forecasting and stock controlling
Information Requirement	Generative solutions	Reference solutions	Rules	Decision support

From a more local and practical perspective, the lead time reduction has long been considered as a fundamental objective in overall business improvement and is a cornerstone in lean thinking. Its benefits include reduced inventories and costs, greater flexibility and responsiveness. In construction projects, shorter lead time could significantly decrease the number of change orders and/or make projects more robust to changes.

Suppliers with different product types have respective strategies to reduce lead time according to their CODP. To realize the supply business goal of time and cost controlling, information circulating mechanism could be a positive force. Compared with the manufacturing supply chain, there is no urgent information need for market sales, but specifications and schedules are quite essential for construction project suppliers. Under the practical demand, CODP could be considered as an Information Decoupling Point (Mason-Jones & Towill, 1999), which indicates the information need both in the forecasting phase and the real-time supply phase, as shown in Figure 5:

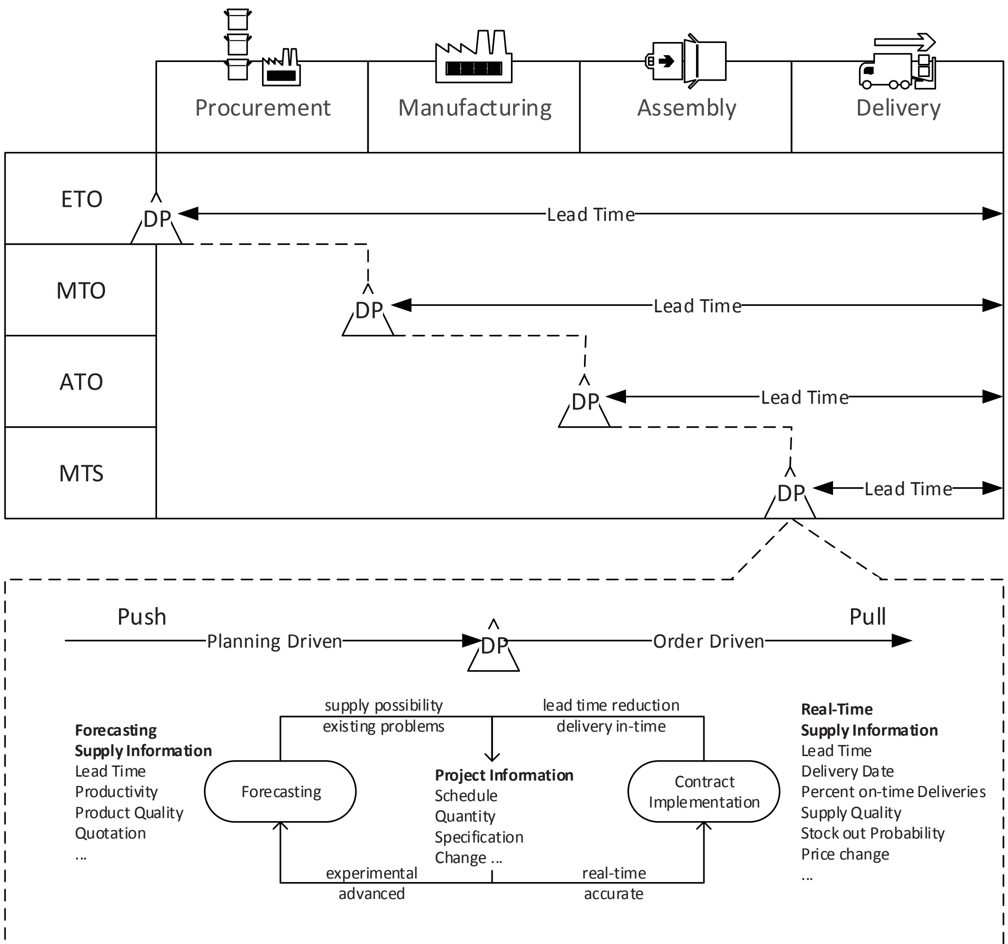

Figure 5 Different product type of CODP and supply information circulating

5.3 CODP-based control strategy associated with IFC model

According to respective supplier characteristics driven by CODP, Classification Management thinking should be introduced to a static model. In the construction manager interface, functions of sub-categories of different types of suppliers should be implemented, and a management indicator according to different Attention Levels also should be set up.

The IFC model is the significant object in BIM-oriented CSC. It can provide high Level of Development (LOD) models to explain project supply demand with 3D presentation and professional parameters, which is quite effective and helpful to ETO and MTO suppliers. From a construction management perspective, it is convenient for GC/CM to check, change and update orders when they are automatically linked to an IFC model.

CODP-based classification associated with an IFC model is able to provide management strategies as follows (see Figure 6):

- Lead time float interval identification: ETO and MTO contain higher lead time float possibility. Fuzzy Theory could be effective to identify delivery time intervals considering different degrees of uncertainty (Szczesny et al, 2015); Conversely, MTS and ATO have narrowed float intervals and the delay possibility can be labeled as a Boolean type with manage requirements of high frequency check.
- Stock control strength distribution: ATO and MTS manufacturers usually hold stock, and on site a certain quantity of stock is also allocated. In these supply modes, stock quantity should be reasonable and real-time managed to reduce delay risk, when the delay label is true.
- Specification/Model LOD provided by project: ETO and MTO, especially the ETO mode, need high specification or model LOD. Providing appropriate LOD project references is the obligation of the construction manager.

- Attention Level setting: it emphasizes the risk management of supply delay as well as induced construction delay and it has an influence on BIM model developing, which is mainly discussed in 6.2.

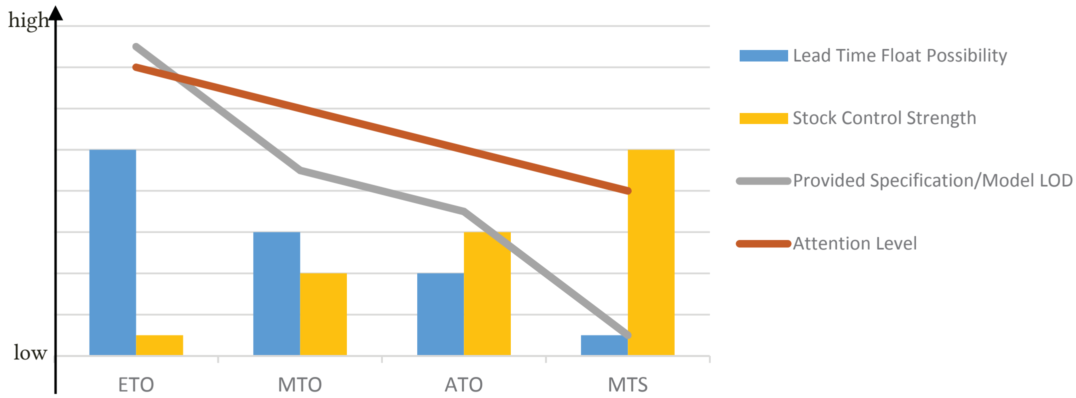

Figure 6 CODP-based classification factors for management strategy

6 Implementation

6.1 CODP-based classification and rule making work flow

A solution for implementing the framework of BIM-oriented CSC modeling is very significant for improving construction schedule performance. Different types of BIM elements can be identified in IFC models with CODP classification thinking (Figure 7). Therefore, it is more convenient to monitor the lead time for supply processes and contact related suppliers in order to avoid possible delay both in the upstream and downstream of CSC. By identifying model elements with supply and logistics information, schedule control strategy, which was previously discussed in 5.3, is able to be applied more visually and efficiently.

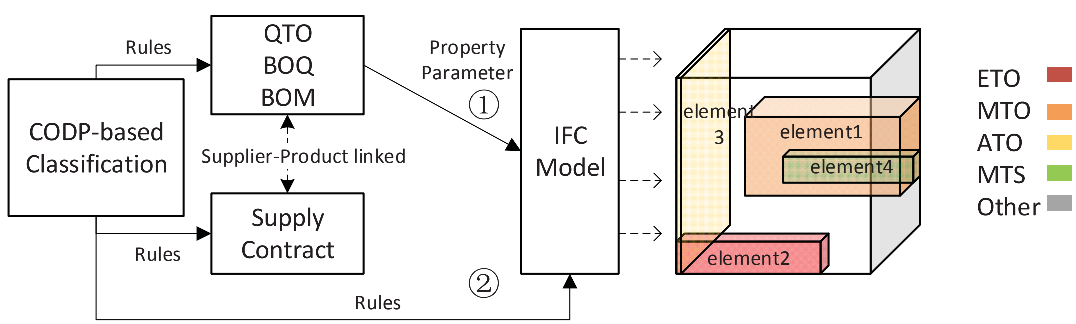

Figure 7 CODP-based supply information for IFC model

CODP-based classification principles will be applied in both QTO/BOQ/BOM (Quantity Take-off/Bill of Quantity/Bill of Materials) documentation and supply contract. Supply contracts should contain the original classification data about the supplier and his or her product. Considering the interoperability of information exchange in the whole supply and construction process, it is necessary that the supply contract and QTO/BOQ/BOM are linked together based on the same classification standard. As it is illustrated in Figure 7, providing new property parameters from QTO/BOQ/BOM to the IFC model is one of the possible solutions to integrate supply and logistics data with BIM (Path ①); applying CODP-based classification rules into the IFC model directly and linking it to other models for practical application is the second possibility (Path ②), which may be more effective to improve interoperability when it starts from design stage.

In practice, every important element should be distinguished according to CODP attributes and visualized in BIM models, in order to provide the foundation for attention visualization and schedule control. How to identify each element and monitor related lead time is a rule-based process. The process of CODP-based classification and rule generation is shown in Figure 8:

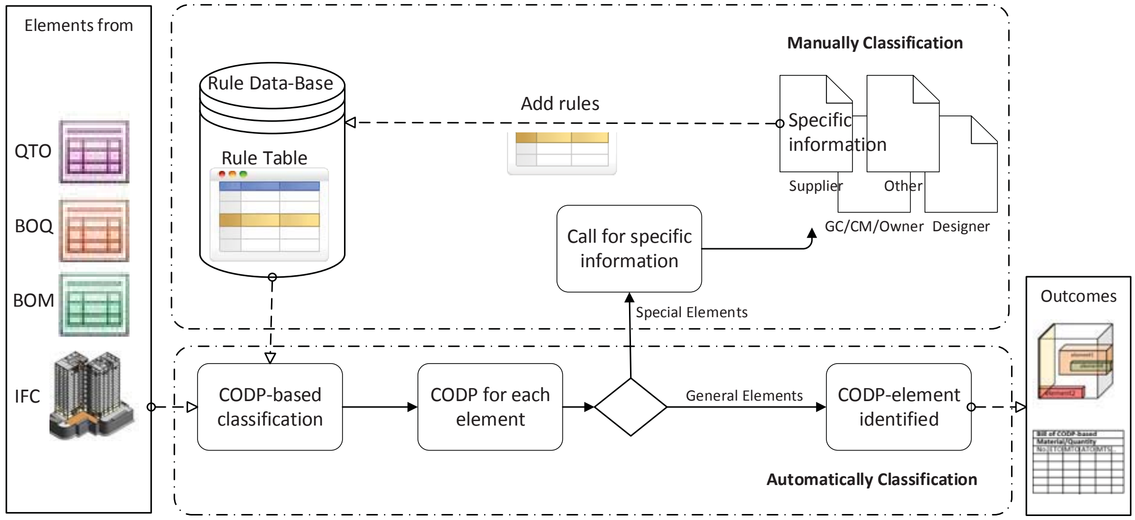

Figure 8 CODP-based classification and rule generation

At first, the form of original rules is represented as a General Rule Table, which contain basic experience-based information for general element classification, such as doors or windows. Through an automatic classification process, each required general element from QTO/BOQ/BOM documents and the IFC model could be identified and added CODP as an attribute. However, in practice there are large number of special elements which could influence the schedule more intensively than general elements. To deal with these special elements, more specific information is needed from suppliers, construction contractors, owner or other participants. Thus the original General Rule Table must be updated and new rules would be added into the Rule Table as well as the Rule Data-Base.

As a result, elements from QTO/BOQ/BOM could be classified and rearranged into Bill of CODP-based Material/Quantity, where information query and insert of Bill of CODP-based Material/Quantity are supported. QTO/BOQ pay more attention to construction items (foundation, beam, shear wall etc.), while BOM focuses more on materials or other objects (cast-in-place concrete, reinforcing steel etc.) of orders. The difference among these documents should be considered when CODP-base classification is applied and the outcomes about Bill of CODP-based Material/Quantity need to be modified according to specific project control purpose.

Meanwhile, element from the IFC model could additionally be visually recognized, so that ETO, MTO, ATO, MTS and other supply type elements can be located in the IFC model with specific supply property parameters.

6.2 Attention Level setting

Attention level setting is associated with the CODP-based classification strategy and the BIM model preparation. A conceptual attention level is illustrated in Figure 6. Commonly, long lead time would force schedules to be frozen over long periods, thus increasing the possibility of schedule changes. For example, ETO supply processes need to be labeled as a higher attention level than other types and attention must be paid to both accurate logistic information acquisition and BIM model developing with appropriate LOD, which means rule-based checking of lead time planning and a BIM model LOD development is the essential task for construction schedule control. This paper provides a basic approach to this initial work for attention level setting, shown as follows:

```
Attention Level
Initial Assignment

for i=element object amount do
  Attention Level
    ETO=  ↑ ↑ ↑ ↑
    MTO=  ↑ ↑ ↑
    ATO=  ↑ ↑
    MTS=  ↑
    Other= unknown
end
```

```
Attention Level
Check and Update

Procedure CheckLOD
if LOD is sufficient for ETO..MTS supplier
   then
      Attention Level=Attention Level
   else
      Attention Level=Attention Level+Risk Value
      Require higher LOD+
      CheckLOD (LOD+)
end

Procedure CheckLeadTime
if LeadTime <= planned lead time
   then
      Attention Level=Attention Level
   else
      Attention Level=Attention Level+Risk Value
      Require Schedule Control Measures
end
```

Figure 9 Basic procedure for attention level setting

6.3 Function mock-up

In order to put BIM-oriented CSC models into use, linking it to a BIM model software platform is a practical step. The mock-up example provides a simple view of function realization, shown as Figure 10. There is both a construction schedule window and a supplier lead time window linked to the BIM model. The supplier lead time management window provides functions of check classification, status view, process view, and lead time calculation, delivery time estimation etc.

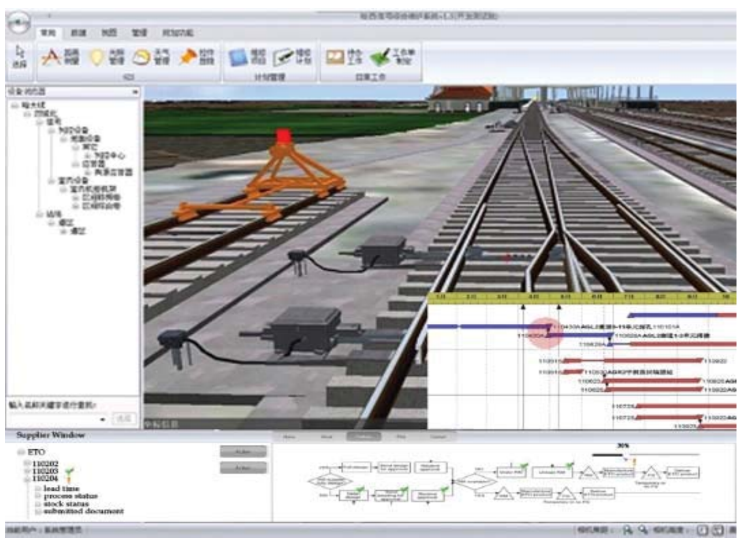

Figure 10 Example of BIM-oriented CSC information viewer

7 Conclusion and outlook

This paper tries to present the ongoing work of a holistic control model for BIM-oriented CSC, which aims to provide accurate, complete and real-time logistics information for construction schedule control. Based on CODP-based classification thinking, this paper analyzes the information need of different supply nodes and presents the strategies of lead time management influenced by uncertainty. To facilitate the modeling process, it is emphasized to integrate IFC model into CSC. The approach focuses on the information exchange process among key vertices in BIM-oriented CSC. Once the future work based on the model bridges the construction schedule with the supply lead time in an open BIM platform, it can support the project management and supply business to achieve their bilateral successful execution. However, there are several further tasks that need to be accomplished after the initial research work: initial models need to be improved with details in the future work; specific supply processes and lead time estimation should be simulated with specific algorithms; solutions or standards of information exchange among different objects need to be worked out. In the future, more industry practices and project cases should be adopted to improve current framework of modeling and function realization.

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