

INTEGRATED PRODUCTION SCHEDULER FOR CONSTRUCTION LOOK-AHEAD PLANNING

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ABSTRACT

Enhancing the reliability of planning is the key to achieving stable construction flow and, subsequently, high productivity and improved product quality. Traditional look-ahead scheduling tools are not suitable for producing robust work schedules. Being aware of the inherent problems in traditional scheduling methods, we propose an improved scheduling tool, the Integrated Production Scheduler system, to help produce quality-assured look-ahead schedules by incorporating integrated information on the availability of resources and information into activities. This tool is developed specially for implementing Lean Construction philosophy in construction process design. Its principles for achieving a quality, timely and transparent schedule are described in this paper. It is based on a distributed scheduling model with the utilization of Internet technologies, such as JavaBeans and XML.

KEY WORDS

Integrated information, scheduler, look-ahead planning, JavaBeans, XML, Internet

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INTRODUCTION

Planning plays a critical role in project management. Its function is to make the construction process more transparent and manageable. Typically there are three levels of planning in project, i.e. project planning, look-ahead planning, and commitment planning. Project planning produces a master schedule that provides a project manager with a panoramic view on project procedures. It also facilitates cost analysis and resource allocation. Look-ahead planning details, adjusts, and optimizes the initial schedule and scopes the work in the near future, normally three to four weeks or so ahead. Commitment planning handles weekly work assignments based on actual resource capacity and completion of prerequisites.

Achieving high productivity in construction is attributed to both the careful design and the successful execution of work schedules. Project planning is too abstract for field superintendents and foremen who need more detailed information to schedule the incoming work as well as allocate resources. Look-ahead planning, as implemented in the Last Planner, is the bridge to link project schedules with commitment schedules. It serves several purposes (Tommelein and Ballard 1997). First, it helps break down project-level activities and shape work flow in the best achievable sequence. Second, it adjusts precedence relationships between activities for optimization and allocates resources in advance to match capacity for each activity. Third, it reduces variability in construction to achieve stable work flow by securing the availability of required resources and information. Fourth, it brings in the coordination among independent work or multiple trades.

Due to lengthy duration and multi-party involvement, construction work is usually exposed to uncertainties. The quality of planning is seldom shielded when projects are bigger and more sophisticated. Work flow is often interrupted by various uncertainties. One of the biggest categories of uncertainties that has been recognized are the discrepancies between anticipated and actual resource/information availability. When certain types of resources (such as manpower, materials, equipment) or information (such as shop drawing, specifications, change approvals) are missing, current work generally cannot proceed until the missing resources or information are available. If such occurrences happen frequently and cannot be effectively controlled, the reliability of the planning would have been severely compromised.

A new evolving philosophy, Lean Construction, has been advocated in recent years. It aims at doing construction work more efficiently and reducing waste in work flow by tackling the inherent flaws in conventional construction management practice. We appreciate this philosophy and in this paper a scheduling tool called the Integrated Production Scheduler system is proposed to help a project manager or contractor make improved look-ahead schedules that implement the Lean Construction philosophy. The principles and objectives for this tool are described and a distributed scheduling model, which takes advantage of the innovative technology in JavaBeans and XML, is presented.

PROBLEMS WITH TRADITIONAL PLANNING

Traditional construction planning is built up on the basis of a conversion model where each activity is a conversion process that converts input resources to a final or an intermediary

product. The conversion process can be divided into subprocesses, which also are conversion processes. Planning at different levels is responsible for identifying the activities and then organizing them in the most efficient way to achieve certain objectives subject to some constraints. This conversion model has been supported by many conventional scheduling tools, such as the Critical Path Method (CPM). As construction is a complicated process, it is not possible to account for all factors in planning. Some implicit assumptions in using these scheduling techniques are as follows: (1) each process or subprocess is conducted and managed independently; (2) scheduling activities is subject to certain constraints, such as precedence relationships between activities, resource availability profile, and client's constraints, etc; (3) preparation for doing an activity has always been adequately made before the activity's scheduled time; (4) each activity is to be duly accomplished.

Traditional scheduling tools do well in project-level planning, which is not concerned with details of resource delivery and information acquisition. However, they are not easily amenable to producing robust look-ahead and commitment schedules. Present CPM-based scheduling tools are not able to track the availability of required resources or information for each activity. This is acceptable if the above assumptions are true. Unfortunately, evidence shows that in practice what happens is hardly consistent with what was estimated at the planning stage. Work flow tends to be fragile and easily deviates from the original sequence. Although field crews make their own efforts to reduce such inconsistencies, the chance of success is remote unless the root cause of the problem has been identified.

The conversion model is incomplete, if not erroneous, for it neglects the physical flow between activities. Construction should be viewed accordingly as a combination of flows and conversions. This view is supported by the new Lean construction philosophy (Koskela 1992). Conversions represent value-adding activities that directly contribute to the accomplishment of certain products. Flows contain hidden activities that either facilitate the conversions (e.g., necessary preparation for the work), or are simply waste (e.g., waiting for the missing resources/information to be available). The task of construction management, therefore, is not only to make each conversion process efficient but also to compress the flow between conversions to reduce waste. As traditional scheduling tools are poor in identifying and managing hidden activities in flow, it is clear that new tools should be developed to make construction process more transparent and efficient, and hence manageable.

INTEGRATED PRODUCTION SCHEDULER SYSTEM

WHO IS THE INTEGRATED PRODUCTION SCHEDULER?

The Integrated Production Scheduler (IPS) refers to the person or group who makes construction schedules with integrated information to achieve reliable production process, higher productivity, and improved product quality. For a better understanding of who the IPS is and what his duties are, the following aspects are helpful. First, the IPS specializes in construction planning and scheduling. He can act on behalf of various trades, e.g., project manager, contractor, subcontractors, suppliers, etc. Second, although the IPS is capable of doing all kinds of project planning, we focus on addressing his role in making look-ahead schedules in this paper. Third, scheduling activities with integrated information, which will be clarified later, is what makes the IPS distinctive from traditional schedulers. Fourth, the

IPS takes a production view of construction management and believes that construction flow as a whole can be managed as a production process to which Lean Construction principles are applicable.

INTEGRATED INFORMATION FOR ACTIVITIES IN LOOK-AHEAD SCHEDULES

Dealing with much shorter duration than what project planning does, look-ahead planning studies more detailed processes, along with the corresponding methods and resource allocations, based on the master schedule. Traditionally, activities in look-ahead schedules are identified, sequenced, and displayed in almost the same way as those in project-level schedules. The one and only explicit relationship between two activities is their precedence relationship. To schedule is hence to determine the precedence relationships among activities under the consideration of certain given constraints. There is only one type of information, i.e. **PROCESS** Information which indicates precedence relationships, existing in activities. Figure 1 gives an example of activities with the precedence type information in traditional schedules.

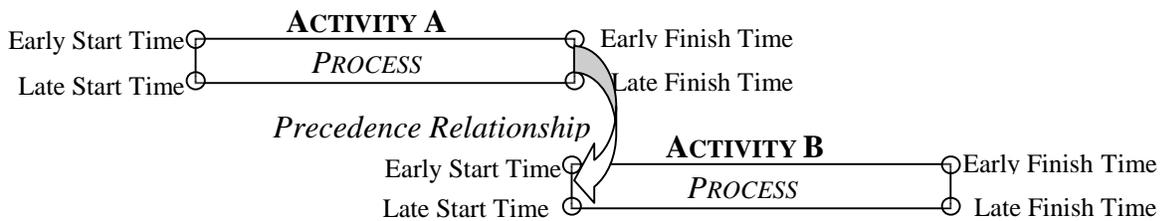


Figure 1: Activities with One Type of Information in Traditional Schedules

Traditional scheduling tools cannot reflect flows between conversion processes. As a matter of fact, a lot of preparation work including resource delivery, equipment setup and information acquisition, etc. is necessary prior to conversion process. However, this kind of activities is usually concealed in schedules and therefore are hard to manage explicitly and systematically. For this reason, time is wasted and additional cost is incurred resulting in the interruption of the conversion processes.

One way to reveal these flows and the hidden activities is to integrate status and pertinent information of the underlying flow to the conversion activities, i.e., **RESOURCES** and **INFORMATION** information. **RESOURCES** refer to ‘hard’ supplies that will be visibly or invisibly converted to a part of a product, including manpower, material, equipment, or space, etc.; **INFORMATION** refers to ‘soft’ supplies that enable or facilitate the execution of certain activities, including contracts, drawings, solutions, or approvals, etc. They both are crucial prerequisites for beginning a conversion process. By managing **RESOURCES** and **INFORMATION**, the IPS is able to manage flows and hidden activities between conversion processes. Essentially, it is the integrated information that makes the IPS scheduling tool substantially different from traditional ones. Consequently, each activity in the IPS schedule has three kinds of information, i.e. **PROCESS**, **RESOURCES** and **INFORMATION**. **PROCESS** supplies the precedence relationship information. **RESOURCES** and **INFORMATION** record

what types of resources and information will be required as well as the anticipated available time for each major resource or information. All relevant project participants are responsible for providing the corresponding information according to their own work schedules. Any activity whose integrated information requirement has not been confirmed will be deemed to have potential for causing flow problems. By this means, the uncertainties associated with resources/information availability can be better managed. Figure 2 shows activities with integrated information in an IPS schedule.

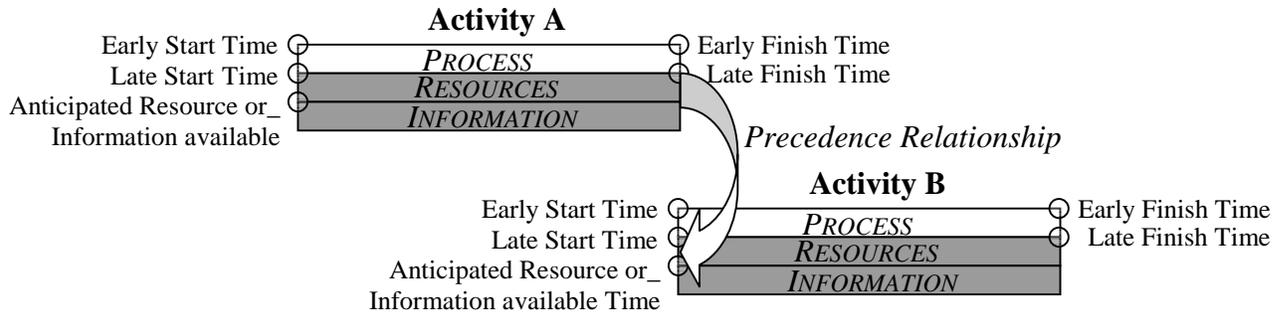


Figure 2: Activities with Integrated Information in an IPS Schedule

LEAN CONSTRUCTION AND THE IPS SYSTEM

The IPS system is developed specially for implementing Lean Construction philosophy, which is the adoption of Lean Production philosophy from manufacturing industry to construction industry. Lean Construction philosophy advocates doing construction work more efficiently by enhancing work flow reliability and productivity, improving product quality, and reducing waste in every aspect, etc. Some tools, such as the Last Planner (Ballard and Howell 1994), have been developed to facilitate the realization of Lean principles in construction. All those previous achievements contribute to our research in the IPS system.

LEAN CONSTRUCTION PRINCIPLES

We refer to Quality, Timeliness, and Transparency as three major principles for Lean Construction philosophy in designing and controlling construction process. They are illustrated as follows:

1. **Quality.** Building quality in planning is a necessary step to enhancing the reliability of work flow and, subsequently, achieving high productivity and improved product quality. It can be realized by removing uncertainties out of schedules by the method of Screening and Shielding.

Screening is to identify uncertainties in schedules. It is the counterpart of stopping the assembly line, when defective products are found, in Lean Production context. In the construction scenario, Screening refers to the decision criteria that determine which activity should be allowed into the look-ahead time frame and which ones should be allowed to move up in time within that time

frame (Tommelein and Ballard 1997). Any activity with uncertainties is treated as a defective product that should not be passed through unless the defective part is cured. In other words, all uncertainties in activities should be removed once identified.

Shielding is to reduce or eliminate uncertainties in schedules. All activities should meet certain quality criteria. As a result, only uncertainty-free, i.e. quality-assured, activities are scheduled and assigned to field crews.

2. **Timeliness.** Coordinating project members in order to achieve timely resource delivery and process completion is another principle of Lean Construction. It resembles the principles in the Just-In-Time (JIT) manufacturing approach. JIT features a Pull-driven mechanism where flow process are ‘pulled’ forward by downstream processes and resources are provided at the needed time in the needed amount. In construction, traditional process planning is based on a push-driven mechanism. Each activity passively waits for resources/information to become available and its prerequisite work to be completed. When problems arise, it is usually too late to employ timely control. The pull-driven mechanism enables potential problems to be recognized in advance and actions to be taken to rectify them, e.g., expediting resource delivery or redesign processes. It is an essential means to achieving timeliness in construction.
3. **Transparency.** Transparency increases the visibility of errors and stimulates motivation for improvement. Increasing transparency involves two parts: production process and project organizational structure. Facilitating communication is the key here. All parties are responsible for exchanging information to make their work processes more transparent to the others. Substantial change in information channels and the decision making model may be required to better achieve this principle.

PRINCIPLES OF THE IPS SYSTEM

Basically, there are three key principles in the IPS system, i.e. integrated information, activeness and distributed system. Each in turn contributes to the realization of the above mentioned Lean Construction principles in planning. Figure 3 shows the relationship of Lean Construction and IPS principles.

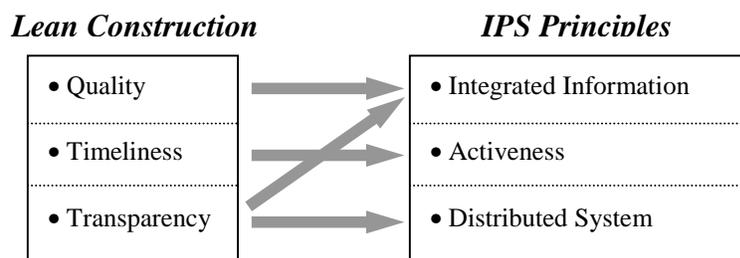


Figure 3: Principles of Lean Construction and the IPS System

1. **Integrated information.** By integrating supporting information on **RESOURCES** and **INFORMATION** to activities, the IPS builds quality in design and improves transparency in process control. Activities are shielded from various uncertainties that cannot be identified and managed by traditional planning approaches. Accordingly, flow process can become more transparent and schedules are more reliable.
2. **Activeness.** The IPS schedule should actively respond to changes in construction in order to achieve timely control on production process. Activities are no longer static elements only for displaying information. They take charge of requesting for information, monitoring changes and notifying the scheduler when problems occur. In some sense, resource and information are ‘pulled’ onto the project. Each activity performs in an intelligent manner to be interactive with the others.
3. **Distributed system.** The IPS system features a distributed decision making system that takes advantage of networking. It promotes communication among project members and increases transparency in decision making process. More parties are involved in providing information and this can be done more expediently (besides the usual site meeting); thus the accuracy of the schedule is improved. Better coordination among information providers is also achievable.

PROPOSED IMPLEMENTATION OF THE IPS SYSTEM

The objectives of the IPS System can be summarized in the following aspects:

1. Produce Look-ahead schedules with integrated information for each activity;
2. Keep track of information on **RESOURCES** and **INFORMATION**;
3. Enhance the reliability in schedules by screening and shielding activities from uncertainties;
4. Diminish variability in process execution and resource delivery by pulling processes, resources, or information;
5. Facilitate coordination among multiple trades; and
6. Establish a distributed scheduling system.

Traditional scheduling tools are not capable of implementing the IPS principles. New technology in JavaBeans and XML has been employed to bring each IPS principle into realization. Figure 4 shows the implementation of the IPS principles with JavaBeans and XML.

JavaBeans: Making Activities Smart

A JavaBean is a portable, platform-independent component model written in the Java programming language. It enables software developers to write reusable components once and run them anywhere (<http://java.sun.com/beans/FAQ.html>, 1997). In many aspects, JavaBeans resemble activities in the IPS schedule. Each JavaBean has two kinds of properties: the attributes that record its static property and the methods that customize its behavior for reacting to certain events. Analogously, each activity in the IPS schedule has

both static attributes (e.g., start/finish time, precedence relationships, and resource/information requirement) and customized methods (e.g., Screening, Pulling, and Shielding). Organizing activities to form a schedule is similar to combining JavaBeans to create an application or a web-based applet. With JavaBeans technology, activities can become active and smart.

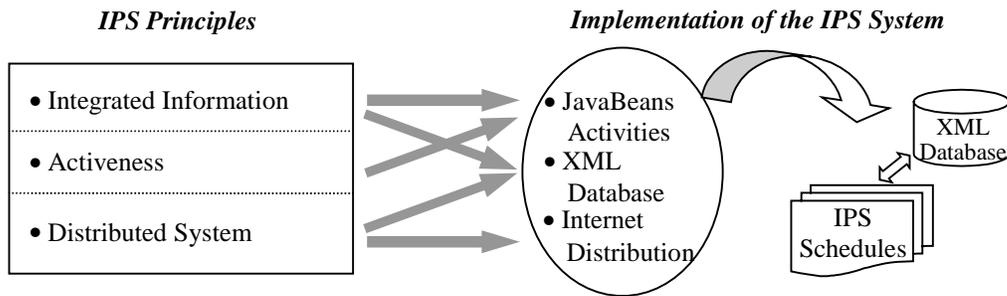


Figure 4: Proposed implementation of IPS principles with JavaBeans and XML

Figure 5 shows how JavaBean activities work in an IPS Look-ahead schedule. In the four-week time frame, detailed activities are selected and sequenced based on the master schedule. Besides **PROCESS** information, integrated information on **RESOURCE** and **INFORMATION** is characterized for each activity. Requests for confirming the availability of resources or information will be sent to the relevant members and the feedback information is stored. The IPS can determine the customized methods for each activity. When certain critical **RESOURCE** information is missing, for example, a notification should be generated to request confirmation. In another case if the completion time for an activity cannot be confirmed, a pulling action should be produced to expedite the process, otherwise that activity as well as its successors will be rescheduled. When all activities have been shielded with confirmed information, uncertainties will be greatly reduced and construction process is more reliable.

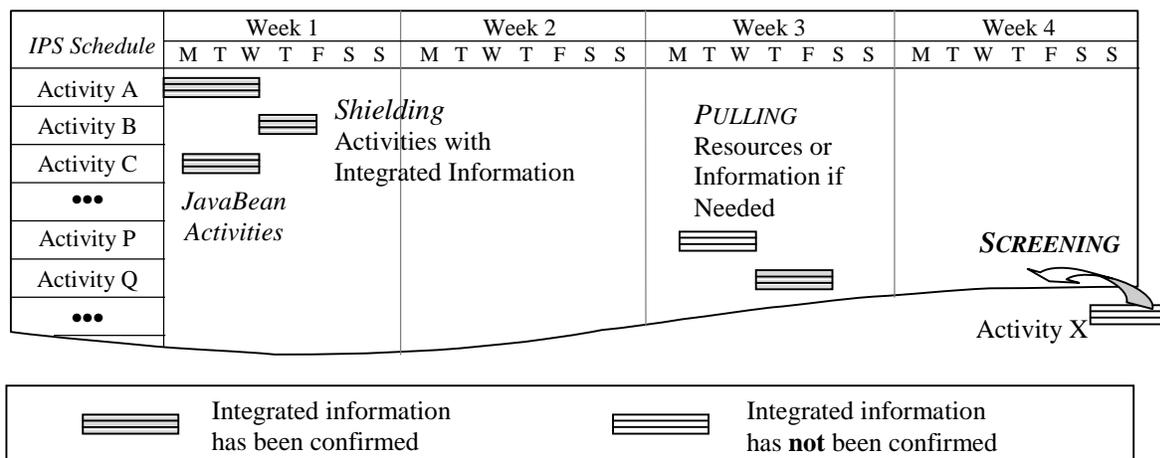


Figure 5: JavaBean Activities in the IPS Look-Ahead Schedule

XML: BUILDING A FLEXIBLE DATABASE

XML is the abbreviation for the eXtensible Markup Language, which is designed to make it easy and straightforward to use Standard Generalized Markup Language (SGML) on the Web: easy to define document types, easy to author and manage SGML-defined documents, and easy to transmit and share them across the Web (<http://www.ucc.ie/xml/faq.html>, 1998). An XML document is a formatted text file, where information is stored in a tree structure. One of its most distinctive features is that users can easily define their own markup tags to create customized text structure. This peculiarity implies that, with the support of certain tools, a set of XML documents could form a database! The tool that converts an XML document into its logic data structure is called a parser. XML is well suited for use with JavaBeans. There are a number of existing parsers that can be used by JavaBeans to retrieve data in XML documents. In addition, XML documents can be distributed and maintained conveniently.

In the IPS system, an XML database is adopted to substitute the use of traditional relational database. Although relational databases have been extensively used in project scheduling for its simplicity and efficiency, its drawbacks should not be neglected. Relational databases are not flexible in that they cannot store an arbitrary number of data for each record. Once the structure of a table is defined, all records generally must have the same number of data items. However, the number of constraints (or data items) for each construction activity is usually different from others. Therefore relational database technology is not best suited to fulfill this task. In contrast, XML database is more flexible. There is almost no restriction on how to structure data in the XML database. In fact, XML documents are merely text files. What the data means will be interpreted by JavaBeans, which are highly customizable to understand the meaning of each markup tag.

INTERNET: FACILITATING COMMUNICATION

The Internet has become a widespread phenomenon that is changing the way activities are carried out. It is increasingly being applied to improve project management. Traditional scheduling is based on a centralized decision making model which lacks timely communication among different parties involved. The project manager has to make a lot of assumptions during the scheduling process; however, many of these assumptions may be wrong. Therefore, the traditional scheduling model is less convincing. The Internet is a platform that can facilitate the communication and collaboration in project management. Exchanging information can be achieved quickly and concurrently. It is convenient to establish a distributed scheduling model over the Internet. Figure 6 shows the structure of the distributed IPS system model. The project manager or general contractor is generally responsible for producing and maintaining schedules. Other members take charge of both executing schedules and providing relevant information. They work closely to ensure each process is reliable and visible to the others. Meantime, using JavaBeans and XML would greatly contribute to this system. They together provide a network-mobile, standard-based, and interoperable component technology to produce reliable, active, and transparent construction schedules.

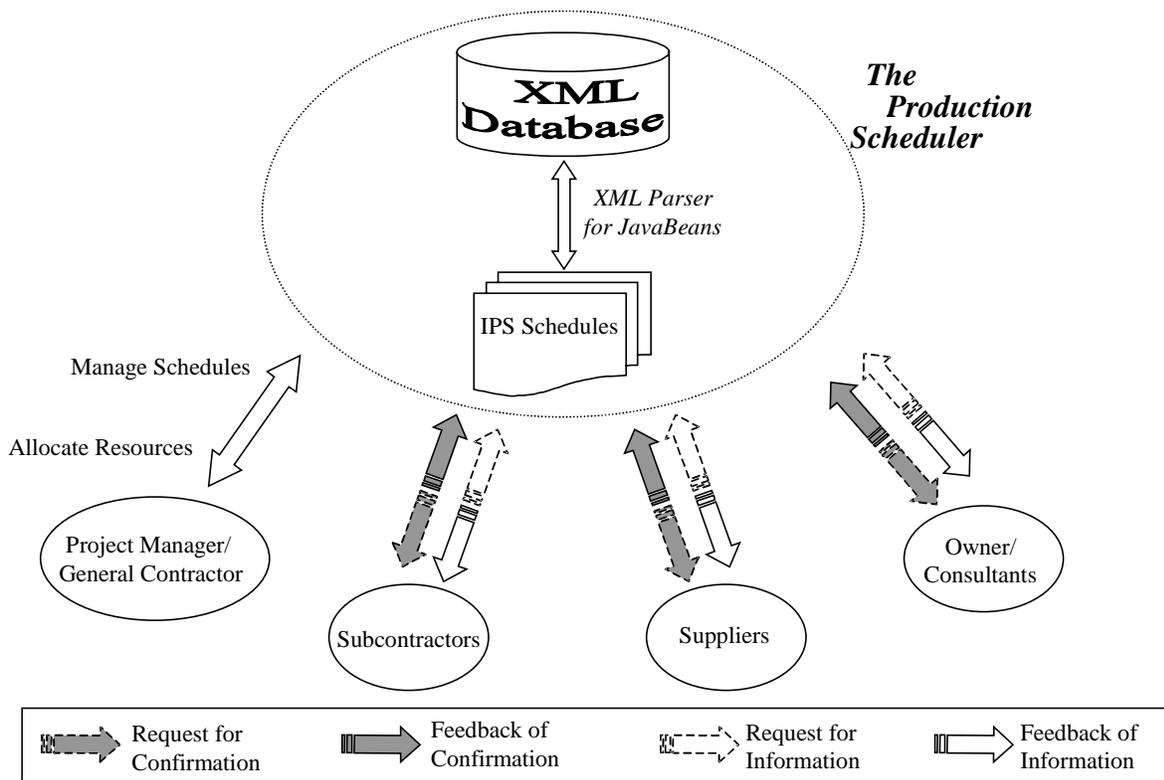


Figure 6: Structure of the IPS system model

PROTOTYPE OF THE IPS SYSTEM

It is apparent that the JavaBeans technology is the key to this scheduling system. To achieve the goals of integrated information, activeness and distributed system, some state-of-the-art development tools have been employed, including IBM VisualAge for Java, Sun JDK1.2.1, W3C XML1.0, Sun ProjectX XML Parser, etc. There are two parts involved in developing the IPS system.

The first part is to build a scheduling and supervisory tool, which produces and maintains a master IPS schedule for project managers. This tool helps visually create Look-ahead schedules with integrated information, retrieve data from the distributed XML database shared by various project members, and update changes in the schedule to reflect the contemporary construction status. Figure 7 shows the prototype of the master IPS schedule. When an activity is created, the project manager determines its underlying integrated information and then sends a message to each relevant project member to provide information. The feedback information will be stored in the XML database and retrieved by JavaBean activities automatically in the future. In this way, uncertainties in the construction can be quickly identified and monitored.

The second part is to set up an online messaging system that allows all project organizations to interact with the IPS schedule. For example, each party should be able to view the latest IPS schedule simultaneously. Moreover, it is necessary that some parts of the

XML database be maintained directly by certain project members who are the sources of the information. The above objectives can be achieved by establishing a server-client model with JavaBean applets running on the server to display the latest IPS schedule information. Each project member contributes to the messaging system by interacting with the server to provide the relevant information accurately and promptly.

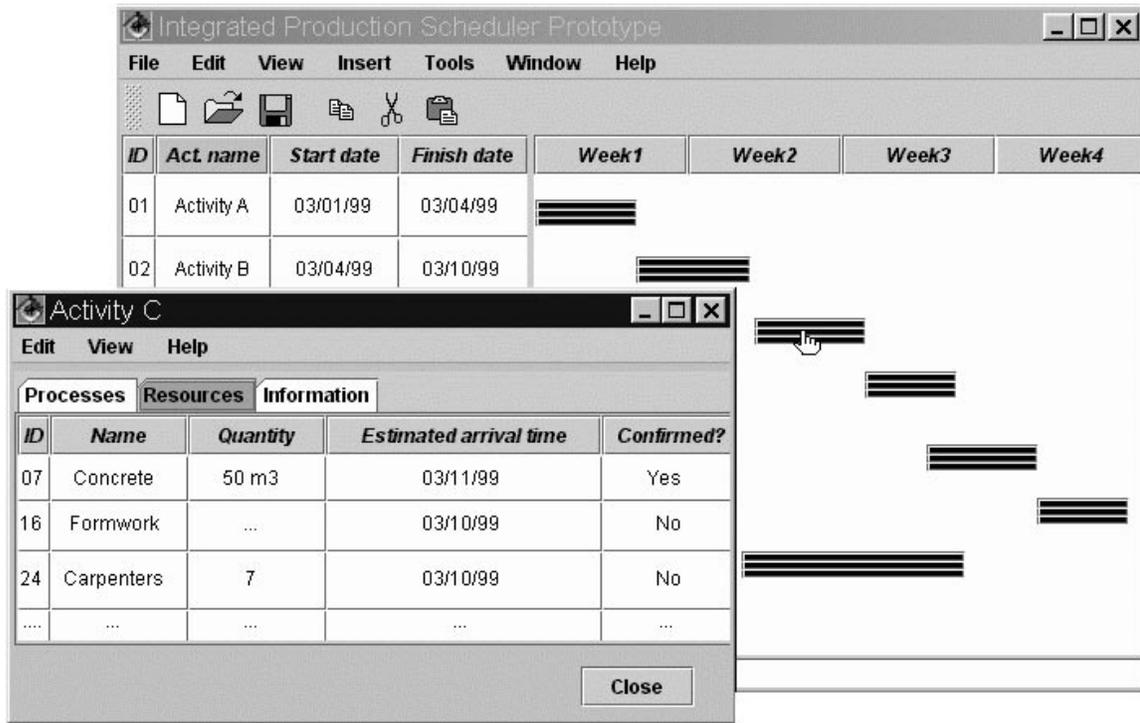


Figure 7: The prototype of the IPS system developed in JavaBeans

CONCLUSION

This paper has presented a scheduling tool, the Integrated Production Scheduler system, for making construction look-ahead planning to implement Lean Construction philosophy. Traditional scheduling tools cannot satisfactorily produce reliable schedules because the availability of resources and information is not shielded in design. By incorporating integrated information into activities, the Integrated Production Scheduler is able to produce robust look-ahead schedules with fewer uncertainties. Three principles of the IPS system have been recognized as integrated information, activeness and distributed system. New technology in JavaBeans and XML, has been employed to facilitate the realization of the IPS system.

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