DISTRIBUTED SCHEDULING WITH INTEGRATED PRODUCTION SCHEDULER

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ABSTRACT

Construction process is vulnerable to uncertainties if the constraints at bottlenecks cannot be effectively identified and removed in advance. The present means of look-ahead planning does poorly in locating constraints hidden in the processes, the supply chain, and the information flow. This problem becomes more acute when the project is very complex and project players are distributed over a large scale. With the intention of implementing Lean Construction principles and the Theory of Constraints, a distributed scheduling tool, i.e. Integrated Production Scheduler (IPS), is proposed to improve the reliability of look-ahead plans, reduce uncertainties in supplies, resolve resource conflicts and alleviate delays in processes. The types of constraints modeled in the IPS are specified and a new method for look-ahead planning called Integrated Constraints Modeling is introduced. By presenting a three-layered structural model, the IPS planning process is addressed in details and the role of distributed systems is also discussed. The full implementation of IPS is based on the Internet technology, especially Java and XML.

KEY WORDS

Integrated Production Scheduler, Integrated Constraints Modeling, Lean Construction, Look-ahead Planning, Distributed Scheduling, Java, XML

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INTRODUCTION

The bottlenecks of construction process are usually located in a few critical activities that have least throughput and take longest duration. It has been recognized that productivity can be increased if these activities are identified in advance and managed properly. With Critical-Path-Method (CPM) based planning tools, bottleneck activities are mostly found in the critical path. Typically, only one type of constraints, i.e. the PROCESS constraints concerning the precedence relationships of activities, is modeled in the CPM. This method has been criticized when used for look-ahead planning because it neglects many hidden activities relating to resource supplies and information acquisition in the work flow. Without addressing these hidden activities explicitly in look-ahead plans, however, many uncertainties that cause flow variation cannot be controlled and minimized in a predictable way. To solve the problem, it is imperative to incorporate additional information that keeps track of supply chain and information flow during project development. With the supplementary information, two types of new constraints, namely RESOURCES constraints and INFORMATION constraints, are introduced to the traditional look-ahead plans. An improved scheduling method called Integrated Constraints Modeling (ICM) is proposed in this paper as an attempt to substantially enhance the reliability of construction look-ahead plans through the implementation of Lean Construction principles and the Theory of Constraints.

On the other hand, information technology has increasingly played an important role in construction management. Planning is one of the key areas that can benefit from it. Basically, planning represents a decision making process that is responsible for not only task assigning but also coordination of project participants. The present way of planning does not encourage much collaboration among project players due to lack of efficient means to facilitate information exchange. This situation demands a major change of the traditional planning tools in two aspects. One is to create new tools that take advantage of information technology to facilitate decision-making process with enhanced accuracy. The other is to make the tools accessible for all project participants so that they can be actively involved in providing pertinent information. In other words, it is necessary to establish a common database and a distributed system for achieving the above objectives.

To realize a better way of doing construction look-ahead planning, a distributed scheduling tool, i.e. Integrated Production Scheduler (IPS), has been developed with the employment of Internet technology, especially Java and XML. It features real-time monitoring on resource and information flow and a distributed decision-making mechanism that aims to improve the reliability of look-ahead plans, reduce uncertainties in supplies, resolve resource conflicts and alleviate delays in processes. This tool is one of the key enablers to implement Integrated Constraints Modeling in look-ahead planning. A proposed structural model with three interrelated layers, i.e. database layer, look-ahead planning layer, and distribution layer, is addressed in this paper. The role of distributed scheduling is also discussed in terms of multiple distribution strategies, namely automatic messaging, Internet publishing and distributed collaboration. The development of the IPS is attributed to three essential principles, i.e. Integrated information, Activeness, and Distributed system, based on the fundamental Lean Construction principles of Quality, Timeliness and Transparency (Chua, Shen, and Bok 1999).

INTEGRATED CONSTRAINTS MODELING

Constraints are the impediments that hinder a predefined system goal or goals to be achieved. According to the Theory of Constraints (Goldratt 1988), any system must have at least one constraint and the maximum output of the system is dependent upon its weakest link, or the bottleneck. Removing constraint(s) at the bottleneck will effectively increase the system performance. Once the constraint is removed, new ones occur. Therefore, identifying and removing constraints represent a dynamic process that pushes the system output closer and closer to its capacity.

In construction planning, traditional CPM-based scheduling tools assume that project planning and look-ahead planning serve a common goal and therefore share similar constraints, i.e. the PROCESS constraints concerning the precedence relationships of activities. This view is not correct because project planning and look-ahead planning are used for different purposes. Look-ahead planning is more specific in regard to guiding the actual construction processes in which additional types of constraints, e.g. the availability of critical resources and information, should be taken into consideration. Although these additional constraints are not exposed during project planning, they usually have considerable influence on look-ahead plans. Without identifying and removing these constraints explicitly in advance, construction process is vulnerable to many uncertainties that are the main causes of flow variation and productivity decrease.

A practical improvement on the CPM is to integrate new types of constraints that are formerly hidden in the supply chain and the information flow. It involves exploring all the potential constraints that may affect the result of look-ahead planning. This method is distinguished as Integrated Constraints Modeling (ICM) in which integrated information on critical constraints are modeled to achieve reliable plans and transparent process control. By introducing integrated constraints, the ICM is remarkably different from the CPM and more suited to look-ahead planning for the reason that it unveils and reduces lots of uncertainties in the process. The implementation of ICM, however, is harder than the CPM because it is more dynamic due to the factors of integrated constraints. Accordingly, a flexible tool that can help not only to locate the critical constraints effectively but also to supervise and respond to changes timely is required.

Integrate Production Scheduler (IPS) is such a tool that is designed specially for implementing look-ahead planning with integrated constraints. There are generally two types of integrated constraints in IPS. One is the RESOURCES constraint that represents the availability of physical resources, e.g. materials, labors, equipment, and tools, etc. Handling this type of constraints is important for controlling the supply chain and the resource allocation. The other type is the INFORMATION constraint that stands for the availability of information prerequisites, e.g. contracts, drawings, approvals, and solutions, etc. This type of constraints helps manage the information flow and coordinate the information supporting system. These two types of integrated constraints are crucial in enhancing the accuracy and reliability of look-ahead plans. Figure 1 shows the types of constraints involved in a CPM activity and an IPS activity.

The implementation of IPS is to achieve enhanced productivity, timely collaboration and reliable production process through reducing uncertainties in work flow, making quality assignment and reliable schedules, facilitating project control and coordination, and increasing transparency in management. These objectives were recognized as three fundamental principles, i.e. Quality, Timeliness and Transparency (Chua, Shen and Bok, 1999), on which the Lean Construction philosophy is based. Correspondingly, three intrinsic principles of the IPS were identified as Integrated information, Activeness, and Distributed system (Chua, Shen and Bok, 1999). Integrated information is the key to SCREENING (Tommelein and Ballard, 1997) and SHIELDING (Ballard and Howell, 1998) production to make quality assignments with the Integrated Constraints Modeling. Activeness is essential for PULLING (Tommelein and Ballard, 1997) resources and information to reduce uncertainties in the supply chain and the information flow. Distributed system enables transparent planning and collaborative process control with improved accuracy and accessibility on look-ahead plans.

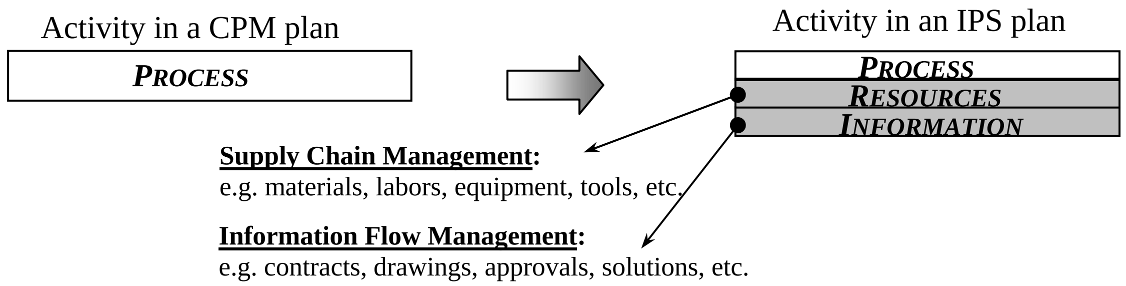


Figure 1: Different Types of Constraints Modeled in a CPM activity and an IPS activity

PROPOSED IPS STRUCTURAL MODEL

Integrated Production Scheduler is built upon Internet technology, especially Java and XML. Java is an object oriented programming language that is robust, secure, high performance, architecture neutral, distributed, and portable. It is well suited for network application under distributed environment. Its intrinsic intelligence through the event delegation model makes it a powerful tool to write active objects that are able to perform programmatic actions on trigger of many kinds of events. XML is an emerging data technology that has received extensive attention by the computer industry in recent years. It is an extensible, structured, platform neutral, and distributed data structure that is an excellent choice for interactive with Java. These two technologies provide tremendous opportunities for accomplishing new types of applications on the Internet.

Java enables IPS to create intelligent construction activities that are capable of monitoring and reacting to real-time changes in the look-ahead plans. Each activity can be designed as a JavaBean, which is a portable and reusable component model for Java objects. The rich features of JavaBeans enable many advanced functions to be implemented in IPS that are otherwise difficult to realize before, e.g. SHIELDING and SCREENING activities, PULLING resources and information, automatic messaging and change notification to remote parties, etc. XML on the other hand makes it easier to establish a common database shared by all project players. It reduces the fragmentation of data storage and increases the integrity of data sharing. The use of XML database dramatically changed the way that data are viewed, processed, transported and managed.

A proposed structural model for IPS is illustrated in detail with three functional layers, including database layer, look-ahead planning layer, and distribution layer, as shown in the Figure 2. For simplicity, only a small number of JavaBeans are described in the model but they adequately represent the core components necessary for understanding the whole process of IPS look-ahead planning.

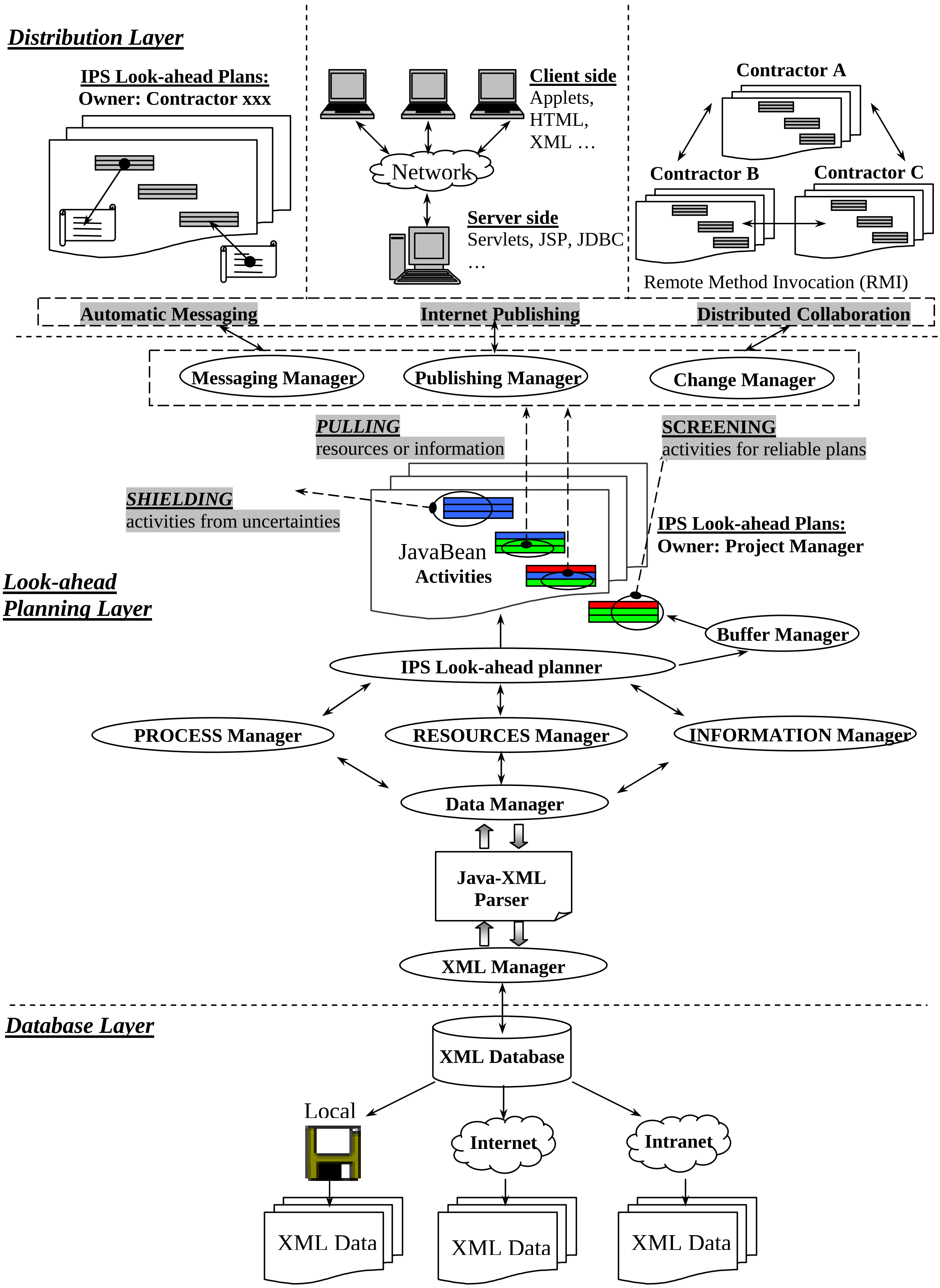
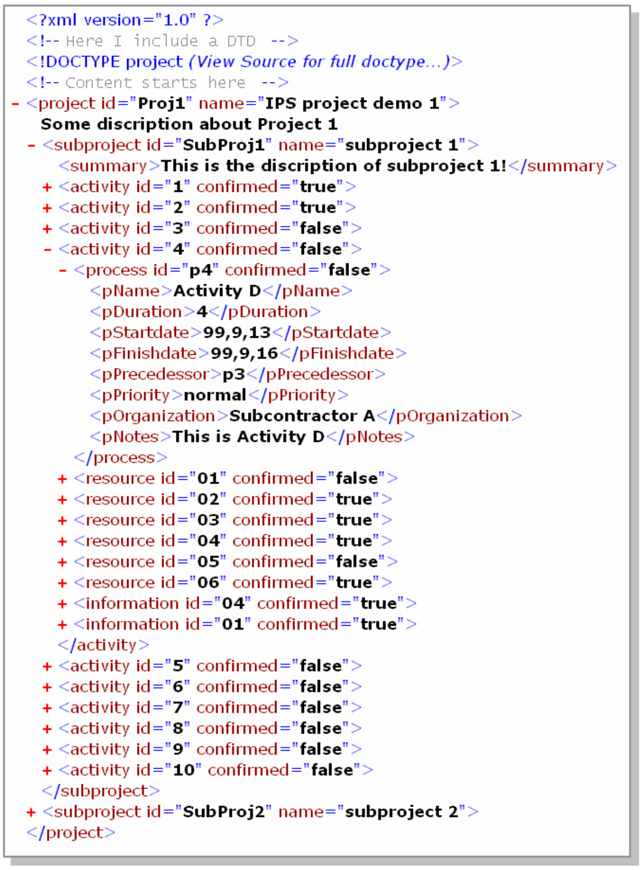


Figure 2 The Structural Model of Integrated Production Scheduler

DATA LAYER

The basic elements of the IPS database are XML files. Figure 3 shows the hierarchical structure of an XML file that stores customized project information when displayed in a supported browser. Consisting of many XML files, the IPS database stores project data in a way different from conventional project database. Most data files are not kept in the local machines but distributed on the Intra/Inter-net. The physical locations of the data are recorded and managed by a specific JavaBean called XML Manager, which is an intermediary broker that separates the handling of data processing and data storage. In this way, it is virtually not important for other JavaBeans to know where and how data are stored as they can always access the required data through XML Manager. Besides storing and retrieving XML files, the XML Manager is also responsible for organizing data to form different levels of project information. Security authority is established and each project member will be granted to certain level of data accessing permission.



```
<?xml version="1.0" ?>
<!-- Here I include a DTD -->
<!DOCTYPE project (View Source for full doctype...)>
<!-- Content starts here -->
- <project id="Proj1" name="IPS project demo 1">
   Some discription about Project 1
  - <subproject id="SubProj1" name="subproject 1">
      <summary>This is the discription of subproject 1!</summary>
    + <activity id="1" confirmed="true">
    + <activity id="2" confirmed="true">
    + <activity id="3" confirmed="false">
    - <activity id="4" confirmed="false">
      - <process id="p4" confirmed="false">
          <pName>Activity D</pName>
          <pDuration>4</pDuration>
          <pStartdate>99,9,13</pStartdate>
          <pFinishdate>99,9,16</pFinishdate>
          <pPrecedessor>p3</pPrecedessor>
          <pPriority>normal</pPriority>
          <pOrganization>Subcontractor A</pOrganization>
          <pNotes>This is Activity D</pNotes>
        </process>
      + <resource id="01" confirmed="false">
      + <resource id="02" confirmed="true">
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      + <information id="01" confirmed="true">
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    + <activity id="9" confirmed="false">
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  + <subproject id="SubProj2" name="subproject 2">
  </project>
```


Figure 3 An XML File Storing Customized Project Data Displayed in a Browser

LOOK-AHEAD PLANNING LAYER

In look-ahead planning layer, data are extracted from XML files and handled by many JavaBeans for different purposes. This is the cornerstone for look-ahead planning. Basically, it involves three functional sub-processes, i.e. data handling, look-ahead planning, and messaging.

Data handling

Upon receiving a request for data accessing, the XML Manager searches the database, retrieves relevant XML files, and returns the results. A JavaBean cannot properly understand the contents of raw XML files without a translation tool called XML Parser. The XML Parser converts XML files to a structured data format that can be read, changed, and saved by JavaBeans. Basic data handling is done by a JavaBean called Data Manager. It filters project data and passes them to three specific JavaBeans, i.e. PROCESS Manager, RESOURCES Manager, and INFORMATION Manager, which deal with real data handling on PROCESS, RESOURCES and INFORMATION respectively. With these three JavaBeans, the prevailing constraints are identified and criteria are set to remove those constraints, especially the ones at the bottlenecks that may cause the most significant impact in process. The constraints identification and handling provides a solid foundation for making reliable schedules in the following steps.

Look-ahead planning

Most of the look-ahead planning work is done by two JavaBeans, i.e. Look-ahead Planner and Buffer Manager. Similar to the CPM planning in first few steps, Look-ahead Planner produces a preliminary path based on the project plan by breaking down project-level activities into smaller activities. Thereafter, integrated information is extracted from RESOURCES Manager and INFORMATION Manager and attached to each activity. New items of integrated constraints can be added to activities where uncertainty is high. Selection of integrated constraints is determined on many aspects, e.g. the uncertainty of upstream processes, the availability of the resources and information, the complexity of production process, the experience of the contractor, and the reputation of the supplier, etc. For each constraint item, a confirmation on estimated available time is requested from the relevant trade. The action of requesting confirmation on the availability of resources and information is called PULLING and the process of solving integrated constraints to reduce the uncertainty of activities is called SHIELDING. With PULLING and SHIELDING, many potential problems inside both activities and the construction process can be perceived and rectified in advance. Figure 4 shows PULLING and SHIELDING resources and information in the IPS.

The Estimated Available Time (EAT) is the key to understand how PULLING and SHIELDING work. If a constraint item has not been confirmed, a request for confirmation will be sent out to PULL the missing resource or information. After the constraint item has been confirmed and its EAT is prior to the deadline, it is then considered as SHIELDED. A SHIELDED constraint item usually has less uncertainty as long as the contractor or supplier keeps his promise. When all the integrated constraints are SHIELDED in this way, the activity is SHIELDED too. Combining SHIELDED activities will form a buffer from which workable activities can be chosen out. When an activity contains unconfirmed constraint(s), however, it should not be placed into the buffer directly or updated in the look-ahead plan automatically unless the constraint has been removed. Preventing unshielded activities being planned without solving the existing problems first is called SCREENING. In the IPS, SCREENING and buffer management is fulfilled by the Buffer Manager. PULLING, SHIELDING, and SCREENING provide an effective way to achieve robust look-ahead plans with less uncertainty, enhanced accuracy, and reliable workability.

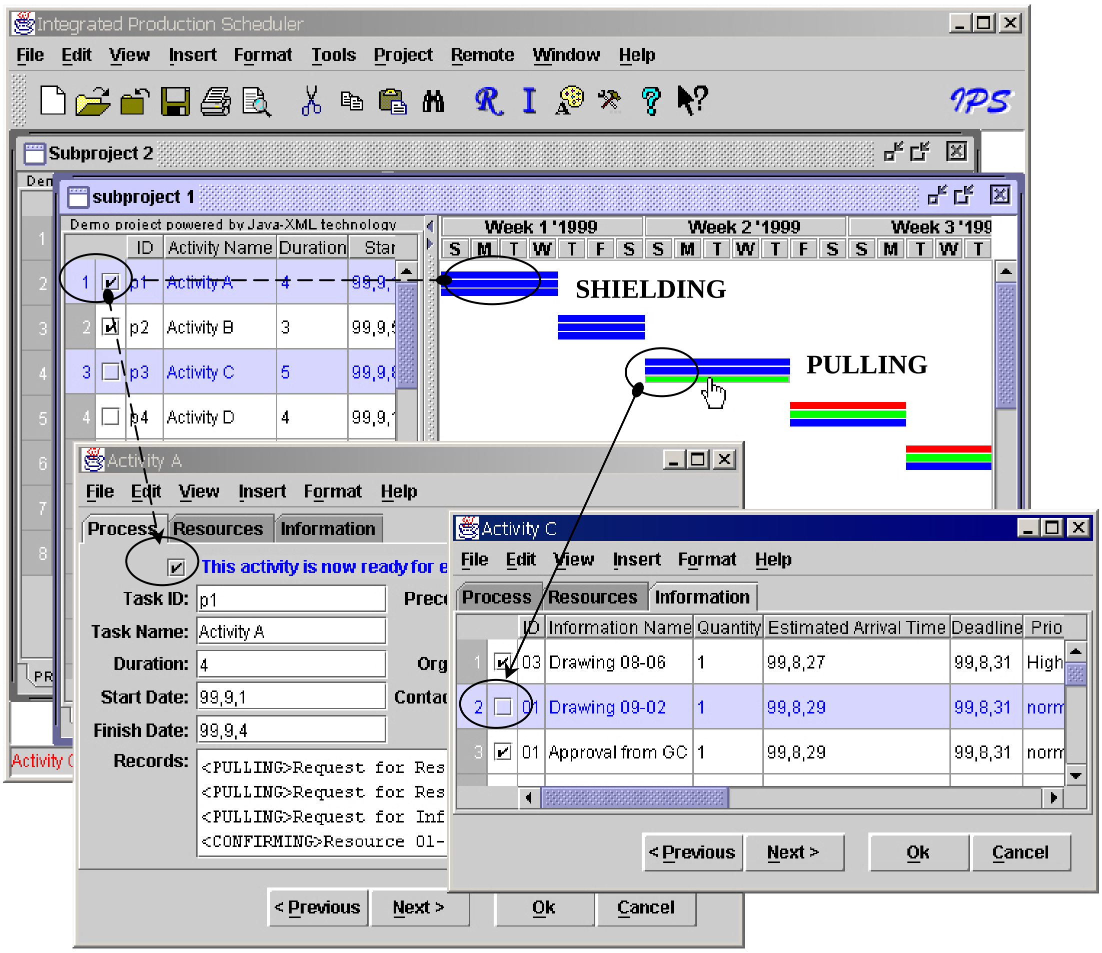

Figure 4 PULLING and SHIELDING Resources and Information in IPS

Messaging

Messaging is a vital function for implementing pulling of resources/information and enabling extensive communication and collaboration among project players. It is built upon Java's advanced built-in networking capability. Three JavaBeans are deployed to conduct a variety range of information exchange among different IPS look-ahead plans. The first one is the Messaging Manager that carries out automatic messaging to remote IPS plans owned by another project member. This involves sending out and receiving standard forms to request or confirm information on PROCESS, RESOURCES and INFORMATION. The second one is the Publishing Manager that updates project information onto the web therefore others can view the latest project status using a browser from anywhere. The third one is the Change Manager that can make all the affected IPS plans at remote side aware when a change happened. Through these three messaging JavaBeans, the scope and the depth of project collaboration are greatly expanded.

DISTRIBUTION LAYER

At the distribution layer, a transparent decision-making environment is to be set up to accomplish high-level collaboration through the utilization of Internet technologies.

Distributed systems are helpful for constituting an improved planning process in many respects. Firstly, distribution of database makes data collection and data sharing more convenient. Secondly, the accuracy of planning will increase if the sources of data can be timely accessed and their opinions are considered. Thirdly, uncertainties will be reduced when all project participants know exactly what the work is going on. Fourthly, the quality of work can be observed and tracked. Fifthly, communication is faster. Sixthly, collaboration becomes more active and transparent.

Based on the Java technology, IPS is capable of being distributed on the Internet and portable on various platforms. The strategies to distribute the IPS systems can be summarized in three levels, i.e. automatic messaging, Internet publishing, and distributed collaboration.

Automatic messaging

Automatic messaging represents automatic information exchanged between two IPS plans via the network. With the intelligence of JavaBeans, each IPS activity can be customized to listen to many kinds of events, e.g. plan updated, confirmation received, new resources/information missing, or deadline expired, etc. Reacting to the events is automatic and instant. Automatic messaging is necessarily needed otherwise updating plans would be less efficient and time-consuming. It involves setting up a server and project players connect onto the server as clients.

Internet publishing

Internet publishing enables project information available to the public on the Internet. It is a fast and practical means to make as many people as possible access project information through browsers. It can also be used to gather data from scattered project members. Due to the increasing popularity of the Internet, Internet publishing has become a convenient way to present and share information among a group of distributed organizations. Figure 5 demonstrates an applet for the IPS look-ahead plan running in a browser. The process of Internet publishing involves setting up a server first and updating project information regularly. Security rules will be set in order to grant different levels of data accessing permissions to different users.

Distributed collaboration

Distributed collaboration is a high-level collaboration strategy in the IPS systems based on the Java Remote Method Invocation (RMI). RMI is a technology that allows a Java object to invoke methods on a remote Java object. It enables more active interaction throughout the project. When changes occur in an IPS plan, they are spread out and reflected on all other affected plans by invoking the remote UPDATING methods. This ensures that all IPS plans are up-to-date. Distributed collaboration is very important and demands a lot of efforts in term of not only adopting new technology but also changing the attitude toward work. The principles of Lean Construction, e.g. Quality, Timeliness and Transparent, only can be achieved when all project participants work closely and interactively with the Lean concepts in mind.

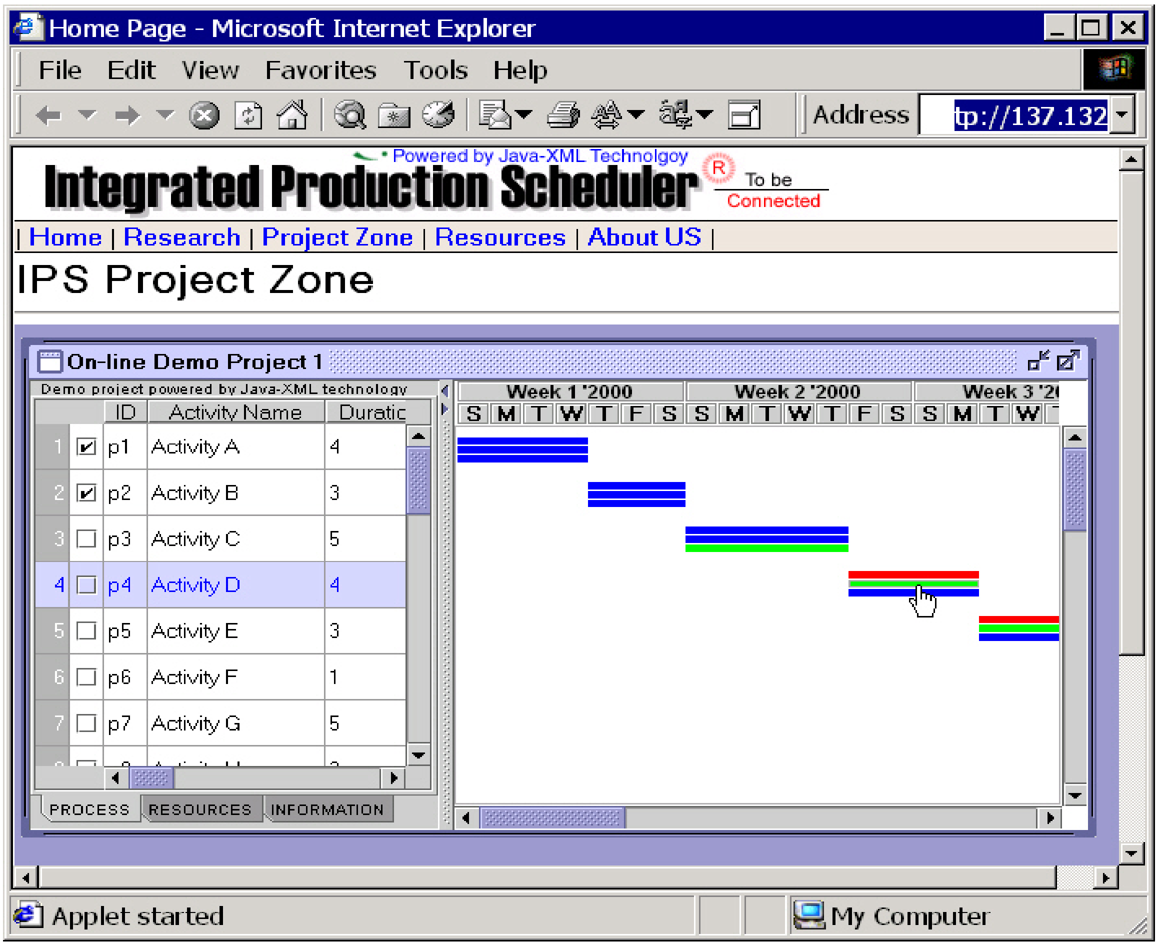

Figure 5 An Applet for the IPS Look-ahead Plan Running in a Browser

CONCLUSIONS

This paper presented a distributed scheduling tool, the Integrated Production Scheduler (IPS), which implements look-ahead planning through Integrated Constraints Modeling. Two types of integrated constraints in the IPS are identified as RESOURCES constraints and INFORMATION constraints. They are used to reduce the uncertainty in resource supplies and information acquisition. A three-layered structural model for the IPS, including database layer, look-ahead planning layer and distribution layer, was addressed. The role of distributed systems in terms of automatic messaging, Internet publishing and distributed collaboration was also discussed. The IPS is built upon Internet technology, especially Java and XML. The development of the IPS is attributed to the implementation of Lean Construction philosophy and the Theory of Constraints.

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