Automating Schedule Review for Expressway Construction

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Abstract: An expressway project is often divided into subprojects with different tendering packages, and carried out by several general contractors that apply different scheduling practices. Each schedule may contain hundreds of activities, each of which is associated with multiple pay items that determine its earned monetary value. With such huge amount of information, the reviewer can only check a sample piece of information, and the quality of review highly depends on the reviewer's experience and devotion. Automated schedule review provides a solution to reduce such problems encountered in the industry. This paper presents a module-based schedule generation and review model, which includes a predefined set of network modules, network builder assistant computer system that helps schedulers manage and reuse the modules to build a new schedule, and another computer system network review assistant (NRA) that helps reviewers review schedules. The NRA uses generalized rule forms to represent the schedule critique knowledge collected from the industry. When potential errors are found, the NRA adopts case-based reasoning to suggest possible correction based on similar cases. The evaluation conducted by the practitioners using real projects indicates that NRA reduces review time, and provides more accurate review on finding activities and related pay items not conforming to standards, and reminding users of important but often omitted activities.

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Introduction

Schedule administration for public agencies in charge of expressway construction includes work of specifying requirements for preconstruction schedules submitted by contractors, reviewing, and approving them before starting construction. It also includes the reviewing and monitoring of periodically updated schedules during construction.

An expressway project is often divided into subprojects with different tendering packages because of many factors such as the volume of work and capital resources involved, work and financial capability of the market, and balancing of excavated and refilled soil. The project is thus carried out by several general contractors who may use different activity names and levels of detail. Even after the division, each schedule may still contain hundreds of activities, each of which is associated with multiple pay items that determine its earned monetary value. With such a huge amount of nonstandardized information, the reviewer can only check for a sample piece of information. The review quality also depends highly on the reviewer's experience and devotion.

Automated schedule review provides a solution to reduce the problem by criticizing the submitted schedules, screening out potential errors, and possibly suggesting appropriate correction. It allows reviewers to be able to concentrate on reduced information that is more likely to contain errors rather than be submerged by information flood. It saves time for reviewers, and also ensures minimum review quality even though it does not necessarily guarantee improved review quality.

Research of automated schedule critique using artificial intelligence techniques has been found in the construction management literature. However, none has addressed the issues of schedule standardization, a primary assumption on the input schedule to be reviewed for an automated schedule critique system. An ad hoc standardization is a promising concept, but very often is hard to implement in practice because it requires professionals involved in changing their daily work practice. Dzeng (2000) developed network builder assistant (NBA) to support the proposed "soft standardization" phase, a phase where standardization is enforced by using encouraging tools and incentive instead of rigid legal documents. The NBA can help schedulers quickly build a preliminary schedule based on predefined network modules that comprise standardized activities and pay items. By using NBA, contractors may save scheduling time and effort, and also fulfill the standardization required by the client. Dzeng and Wang (2003) applied the modules to address the schedule integration issues among multiple contractors and the client's multiple management levels of typical highway projects.

This paper describes our research on developing an automated schedule review system, called the network review assistant (NRA), for expressway construction projects from the perspective of a public agency. The NRA assumes that the given schedule to be critiqued applies standard activities. The schedule may be generated by NBA, or other commercial scheduling software such as *P3* (Primavera Systems Inc. 1999). The NRA can identify potential schedule errors using rule-based reasoning and suggest possible corrections using case-based reasoning.

The paper is organized as follows. It first reviews the related literature on existing schedule review and generation systems.

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Current practices of schedule review are also described at the schedule, activity, and meta-activity level. The paper then presents our proposed module-based schedule review model by describing its representation of schedule data, review principles, and cases. Currently developed applications of the modules are also described and evaluated.

Literature Review

In the construction related literature, there are very few schedule review systems. De la Garza and Ibbs (1990) developed a schedule critique system, called *CRITEX*, which applied the rule-based reasoning, and evaluated construction schedules of high-rise buildings based on a set of critique rules obtained through interviews with several human schedulers. The output of *CRITEX* was a set of critique statements. However, the report did not include suggestions regarding the revision of schedules.

Nevertheless, much literature has been found on principles or knowledge of construction planning and scheduling. Scheduling textbooks (e.g., Ahuja et al. 1994) provide principles and techniques for activity coding, activity sequencing, schedule representation, and resource leveling. Many AI-based construction planners were also developed, such as *Construction Planex* (Zozaya-Gorostiza et al. 1989), *HISCHED* (Shaked and Warszawski 1995), and *CasePlan* (Dzeng and Tommelein 1997). Knowledge of these planners targeted the construction of buildings or process plants. Except for *CasePlan*, the planners applied the rule-based reasoning and created an activity network for a given project described using a predefined set of component hierarchy. Although no planners have focused on the construction of expressways and addressed schedule review from the owner's perspective, some of the planners' general planning principles have been used in this research.

Schedule Review Practices

This section describes our study of schedule review practice from the perspective of a public owner. The observation is based on the schedules collected from, and surveys and interviews conducted at the Taiwan Area National Expressway Engineering Bureau (TANEEB), a primary public work administration agency in Taiwan. Other variations to the practices described thereafter are also possible.

The TANEEB is primarily responsible for the administration of all newly developed national expressways in Taiwan. In the 2001 fiscal year, TANEEB carried out expressway projects of approximately $16,940 million (United States dollars) (35.82% of the transportation and communication infrastructure spending). The agency has been administrating 134 construction contracts with a volume ranging from approximately $140,000–$600 million.

A typical expressway construction schedule consists of hundreds of activities, each of which is associated with multiple pay items. Reviewing such a schedule is a time-consuming job. Thanks to the increased power and proliferation of computers, many schedules nowadays are submitted in both paper and electronic forms, which allow faster search, filtering, and modification of scheduling data. However, the process still requires a reviewer experienced both in the field and in using scheduling software to find potential errors. Such a qualified reviewer is not easy to find. Most reviewers are either highly experienced in the field but not in software, or vice versa. A combination of the two types of reviewers as a review team is common practice.

Reviewers of different parties emphasize different review aspects. The contractor's scheduler may focus on the accuracy of detailed input such as activity durations, network logics, and allocation of pay items to avoid unintentional input errors. The contractor's project manger may focus on the coherence of work scope with the contract, availability, and flexibility of resource use, and feasibility of work approach. The *A/E* (architect/engineer) may focus on, in addition to the contractor's focus, finding the distorted part of the schedule (e.g., unreasonable float or critical paths) to protect the owner's right. The owner's review may focus on the coherence of schedule format and content with the contract specifications, provide a foundation for schedule integration, and earn value calculation. Much attention is also paid to critical paths, cash flow, and work interface with other contractors.

This research addresses primarily the review of the *A/E* and the owner. Based on interviews with schedule reviewers and reading past interim review reports, we have collected items which reviewers often review, or contractors often intentionally distort with or unintentionally made mistakes on. Readers may refer to Dzeng (2000) for a complete list of review items. The Appendix divides these review items into 12 categories, and lists at least one review item example for each category. These categories are further divided into three groups: schedule level, activity level, and meta-activity level. The number in parentheses following each category name indicates the total number of critique items established in this research.

Schedule Level

Format

This type of review includes checking the completeness of schedule documents, required signatures, network representation format (e.g., precedence diagramming method), and notations for activity nodes.

Activity

Some owners may require awarded contractors to use standard activity names or codes for efficient schedule integration. This is especially useful for a large expressway project where multiple general contractors are involved and schedule integration is necessary. This type of review ensures correct activity names or codes be used, and the use of nonstandard activities in the submitted schedule be justifiable and their codes follow the standard code structure.

Milestone

This type of review ensures that important milestones, especially those specified in the contracts, be defined clearly in the schedule and their dates conform to contract agreements. Examples of such milestones are "notice to proceed," "open to traffic," "road closure," and activities affecting other contractors' work.

Important-but-Often-Omitted Activity

Some important activities are often omitted in the schedule because they are not directly related to the main expressway structure. These activities are considered important because they may be on the critical paths and greatly affect project progress. Examples are "reallocation of utilities lines," "land acquisition," registration of current conditions of neighboring facilities, procure-

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ment activities, materials review and test, etc. Such review ensures that these activities be clearly identified and their scheduled dates be appropriate.

Critical Path

This type of review prevents the critical paths from being unreasonable due to intentional or unintentional distortion by inputting inappropriate activities, durations, relationships, and time constraints on the paths. Distortion of critical paths may be, while detrimental to the owner, beneficial to the contractor's future claims on change orders. For example, some contractors may intentionally distort critical paths by placing the owner-furnished activities on the paths for their advantage in future claims on the extension of project duration. The review inspects the number of critical paths, arrangement of activities on the paths, and primary equipment allocated to those activities.

Working Calendar

This type of review ensures that the working calendars be appropriate. For example, project durations are counted in the same way (work day versus calendar day) as specified in the contract; work days are correctly set for each week and for each primary trade.

Work Interface

This type of review ensures that work interfaces among contractors be clearly identified and the progresses be specified as agreed.

Activity Level

Activity Duration

This type of review ensures reasonable activity durations and appropriate breakdown of long activities for easier monitoring of work and payment progress.

Activity Relationship

This type of review ensures that necessary sequential relationships be properly imposed between activities and be of an appropriate type (i.e., start–start, start–finish, finish–start, and finish–finish).

Activity Float

This type of review ensures that activities with long free or total floats be appropriate and not the result of missing necessary sequential relationships with other activities or inappropriately imposed time constraints.

Time Constraint

This type of review ensures that time constraints imposed on activities be necessary. For example, some contractors might impose unnecessary time constraints to shorten project duration to meet the specified deadline, or to distort critical paths.

Lead Time

This type of review ensures that necessary lead times required by the specifications or regulations have been allocated, and their lengths be appropriate. Examples are the lead times for submittal review and self-settlement of road embankment after it is finished. Contractors might also impose inappropriate lead times to distort critical paths.

Meta-Activity Level

Pay Item

This type of review ensures that primary pay items be associated with appropriate activities, and their quantities correspond to the specifications and be appropriately distributed. The review may prevent the front-end loading of the contractor's earned value.

Resource

This type of review ensures that the deployment of primary resources match the planned work progress. For example, one contractor may adopt The Advancing Shoring Method for bridge construction and have three activity paths progressing concurrently while there are only two assembled wagons available. Attention should also be paid to the time arrangement of the activities that use the resources shared with other contractors.

Module-Based Network Generation

The term, "activity network module" is similar to the term, "subnetwork" in general or "fragnet" in *P3*, but with a much stronger purpose of motivating contractors to use it to create the main part of a schedule. Each piece of project work may be broken down into a hierarchy of construction units (e.g., superstructure unit or pier column of a bridge). Each construction unit is associated with at least one network module (e.g., "Advancing Shoring Method" module) that describes how the unit can be constructed. The module may be expanded to describe the aggregation of units of the same type (e.g., a series of superstructure unit) by repeating part of its activities (e.g., "box girder cast in place"). A schedule for a project with different types of units can be generated by linking activities of different expanded modules.

Each module includes the following attributes: name, activities, activities' precedence relationships and lead times, recurring times, unit section (describing the location of the associated construction unit; e.g., "Dashu County Overpass 170–175 km"), and unit direction (specifying the associated lane direction; e.g., north). Each activity includes the following attributes: standard code (uniquely identifying the class of activity), counter (uniquely identifying each activity in the same class; required if the schedule is to be readable by commercial scheduling tools that require a unique identification number for each activity), name, type (explained later), duration, duration estimation reference (formulas, factors, or other experience-oriented duration estimation information), associated pay items, and subactivities (describing the scope of the work under the activity). Each pay item includes the following attributes: standard code, counter, quantity, and unit (e.g., ton).

A module includes the attribute recurring times, and an activity includes the attribute type to accommodate the repetitive nature of expressway construction and to reduce the need for contractors' further input when they use modules.

An activity may fall under one of the following four types: normal, repetitive, cyclic, and merging. A normal activity describes the work that is performed once as a continuous process when the module is used. For example, activity "excavation" in the "earthwork" module is a normal activity; i.e., the construction schedule for a section of road usually involves only a single "excavation" activity.

A repetitive activity describes work that is performed discretely, section by section or unit by unit. The number of repetitions is specified by the value of the recurring times attribute of

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the module. For example, the "box girder segment" activity in the "balanced cantilever method" module is a repetitive activity. That is, when the balanced cantilever method is used to construct a bridge, the box girder segments are erected and extended one by one. Such a schedule usually involves repetitive box girder activities.

Cyclic activities describe work that a group of activities are discretely (section by section or unit by unit) performed as a cycle. The number of cycles is also specified by recurring times. A merging activity describes work required by several modules but typically performed as a whole and represented as a single activity.

For example, the "Advancing Shoring Method" module includes normal activities (i.e., "preparation," "approach slab," "barrier railing," "asphalt concrete pavement," "expansion joint"), cyclic activities (i.e., "wagon assembly," "box girder cast in place"), and a merging activity (i.e., "traffic signage"). The "traffic signage" activity is a merging activity. Therefore, even if the module is used more than once (e.g., because the project involves two bridges), the contractor may perform most activities separately while treating the installation of traffic signage as a single continuous activity.

The activity modules and modeling of activity behaviors reflect the common scheduling practice for the expressway construction, and give users better maneuverability and flexibility on reusing standard activities. When implemented as computer software (i.e., NBA), the model allows a scheduler to generate a schedule more efficiently than the conventional scheduling software. Much information such as activity's code and name, and common pay items and resources can be predefined in the module, and be reused without manual input. The information regarding activities' location, lane direction, and counter can also be defined at the module level, and be automatically propagated to the module's activities when the module is reused. Activities not only can be managed by WBS (work breakdown structure) or their codes, names, or times, but also by module. Readers may refer to Dzeng et al. (2004) for more details on the implementation and performance evaluation of NBA. The next section will focus on the proposed module-based schedule review system.

Module-Based Schedule Review

The reviewers review the aforementioned review items mostly based on, in addition to the contract specifications, their individual, subjective experience. Thus, the same schedule may receive different review opinions from different reviewers. The review of "Format and activity float" often requires subjective judgment. The review of "Format," "Activity," "Milestone," "Important-But-Often-Omitted Activity," "Working Calendar," and "Lead Time" is often straightforward but requires careful list checking. The review of "Work Interface" and "Resource" is more complex and requires knowledge about the detailed project data. The review of "Critical Path," "Activity Duration," "Activity Relationship," "Time Constraint," "Activity Float," "Pay Item," and "Resource" often involves inspecting a large amount of data, and in practice only samples are checked (e.g., checking only the activities allocated with a high monetary distribution of pay items).

Automated review is not suitable for each of the aforementioned items. By considering the feasibility, desirability, and cost effectiveness, we evaluated each type of review item to determine if the review of an item was suitable for automation. Automation is feasible when the data being reviewed are specific, static (e.g., fixed names or codes), in digital form, and require little subjective judgment. Examples are checking the "milestones" (e.g., notice to proceed), "Important-But-Often-Omitted Activities" (e.g., submittal review), and "Lead Time" constraints set by the owner's general specifications. Automated review is desirable when the items involve a large number of data (e.g., "Pay" Items). The filter and sorting functions provided by commercial scheduling tools help in this regard to some degree. The degree of automation may be further increased if batch commands or template were set up appropriately for reuse. Cost effectiveness concerns the efforts required to implement the automated function for reviewing of an item, including those for software development, standardization, or work process reengineering, and the resulting benefits such as time saved, cost reduced, accuracy increased, or quality improved by the automation.

Automated review of most "Format" items is not currently feasible because paper documents, physical signatures, and subjective judgment (e.g., clarity) were involved. The review of "Critical Path," "Activity Time Constraint," "Activity Relationship," and "Work Interface" may be feasible but not recommended because they varied from project to project, and a considerably large amount of data input is required in order to be feasible. For example, critical paths vary from project to project for expressway construction. They may be more similar to each other if each project comprises only a single structure (e.g., a project with only a bridge and without any road and tunnel). However, most expressway projects in Taiwan consist of construction of at least a road and a bridge because of the geographic characteristics. A project with multiple roads and bridges or tunnels is also common. Different combination of the structures, geographic characteristics of the sites, levels of resources deployed to the projects, and contract durations may result in different critical paths. Automated review of critical paths also requires much more detailed input than schedulers are willing to supply. If the automated review model is to adopt the rule-based reasoning approach, rules that determine the appropriateness of critical paths based on these inputs are complex and unclear, and no research has been conducted on this subject. If the model is to adopt the case-based reasoning (CBR) approach, a very similar previous project needs to exist for the model to be able to determine if the critical paths in a new project are appropriate.

Other items are more suitable for automated review. They can be reviewed automatically if the schedule is represented digitally using standard activity names or codes. The proposed NRA is a module-based schedule review model. It assumes that a schedule to be reviewed is generated based on the predefined set of standard activities. The model accepts an input schedule that is generated using NBA or other conventional scheduling tools such as *P3* as long as the schedule conforms to the standard codes for activities, pay items, and resources.

The NRA reviews a schedule based on a predefined set of review rules, cases, and a checklist. A set of review rules was created for each of those recommended review items. The review rules identify the potential errors and suggest possible revisions based on predefined values, formula, or a CBR process. The checklist prompts an NRA user a list of review items that were not automated and should be inspected manually. The intention of NRA is not to replace human reviewers but to facilitate their review work by screening out potential errors and making appropriate suggestions, and thus to improve their review efficiency and effectiveness. A minimum review quality may also be main-

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tained for the agencies that lack engineers who are experienced both in site and computer.

The next two subsections describe how the review principles are represented as rules and how CBR facilitates the rule-based review.

Representation of Review Principles

The NRA represents the principles for reviewing the items that are recommended for automation as rules. A general form of a review rule comprises four parts: rule application condition, object application condition, review statement, and critique reason.

The **rule application condition** describes the characteristics of a project where the rule can be applied. For example, the rule "2 months should be reserved for the installation of expansion joints" is only applicable for a project comprising a bridge. The **object application conditions** describe the characteristics of objects where the rule may be applied. For example, one rule may be applicable only for activities with a name string containing "install." The **review statement** is an "if-then" statement, where if the applicable objects meet the *If* condition then the process proceeds with the *Then* statement. For example, one review statement may specify that the planned start dates of weather sensitive activities should avoid July and August when typhoons are common in Taiwan. The *Then* part of the statement may be a general suggestion or warning text, or a specific corrective advice of value for certain object attributes. The values may be predetermined and embedded in the rules, or dynamic values calculated based on the CBR results. The **critique reason** provides explanations that justify the critique statement. For example, one critique reason may be "General specifications require a lead time of at least 45 days for self-settlement of road embankment after it is finished."

The **rule control setting** determines the behavior of the rule during the system run time. The following lists available choices and describes the behavior of rule when a specific setting is on.

1. *Mandatory?* All the cases or objects, and those that are used to suggest appropriate values for the reviewed schedule need to conform to the rule.
2. *Activated?* The rule will be used to review the schedule. A mandatory rule is activated by default, but nonmandatory rules need to be activated by the user.
3. *ShowGeneralSuggestion?* The predefined explanatory text will be displayed or recorded in the log when the *Then* part of the rule is executed.
4. *CBRValueSuggestion?* When the *Then* part of the rule is executed, a CBR process will be performed to obtain an appropriate suggestion value for the reviewed object attribute values.

The "*If–Then*" statement of a review rule may be expressed in one of the three general forms.

1. If there does not exist at least one object of class *Cx* with attribute *Tx* whose value meets specifications *Sx*, then perform action *Ax*. For example, if there does not exist an *Act* with attribute *name* comprising string "notice to proceed," then report a warning message. This form of rule ensures some information required by the owner is not missing from the schedule. Rules under categories of "Milestones" and "Important-But-Often-Omitted" activities are expressed in this form.
2. For all objects of class *Cx* with attribute *Tx* whose value meets specifications *Sx*, perform action *Ax*, where the specifications *Sx* are statically predefined. For example, for all acts whose planned duration is greater than 30, then report act's name, WBS code, and activity code; where "greater than 30" is a predefined, fixed specification unless changed by users. Rules checking inflated "Activity Duration," "Float," and "Lead Time," and "Minimum Lead Time" required by the general specifications are expressed in this static form.
3. Form 3 is the same as 2 except that the specifications *Sx* are dynamically predefined. An example is: "report all standard activities whose durations differentiate from the average durations of corresponding activities of similar cases for more than 3 s.d.," where the actual reporting threshold value for each type of activity can only be known at the run time depending on the cases available in the system library. Rules checking the appropriateness of activity durations are expressed in this form and the specifications are dynamically determined based on CBR. Rules checking the appropriateness of relationships and pay items, and the use of standard codes are also expressed in this form, but the specifications are dynamically determined based on the current modules of the system. The specifications for rule checking the number of cycles or repetitions of modules depend on the reviewer's input at the run time.

Case-Based Reasoning

The processes of dynamically determining specifications based on the reviewer's input or standard modules are straightforward and primarily involve database mapping and retrieval. The process of determining specifications that are based on cases is more complicated because it involves determination of similarity between cases and what cases should be used. Currently the primary use of CBR in NRA is to determine the appropriateness of the use of modules and activity durations.

Like *CasePlan* (Dzeng and Tommelein 1997), similarity between two cases can be measured at the component level or project level. Similarity at the higher level is a weighted average of similarity at the lower level. For example, similarity between two cases is a weighted average of similarity values between their corresponding components (i.e., road, bridge, and tunnel).

The similarity measurement (i.e., weights) may be different for the task CBR is applied for. Current NRA applies CBR to the review of module use and activity duration, which may apply different weights. In general, attributes that may receive higher weight include road's length and pavement type, bridge's length, superstructure method, and pier-foundation type, and tunnel's length and excavation method, and researcher's name and allocated quantity.

The appropriateness of module use and activity duration in a schedule may be reviewed based on the corresponding values of similar cases based on CBR. For a new case that uses certain modules, the NRA will not consider it inappropriate if at least one similar case has used the same modules. Reviewers may adjust the reporting threshold by requiring NRA to find more cases that used the same module. The NRA will not consider the number of repetition or cycles inappropriate if the number falls within the range applied in similar cases. Reviewers may also adjust the reporting threshold by changing the cutoff point for the range.

The NRA considers activity duration appropriate if it does not differ from the average duration of corresponding activity in similar cases for more than 3 s.d., i.e., if the number of qualifying cases is large enough, it is unlikely that the activity duration falls

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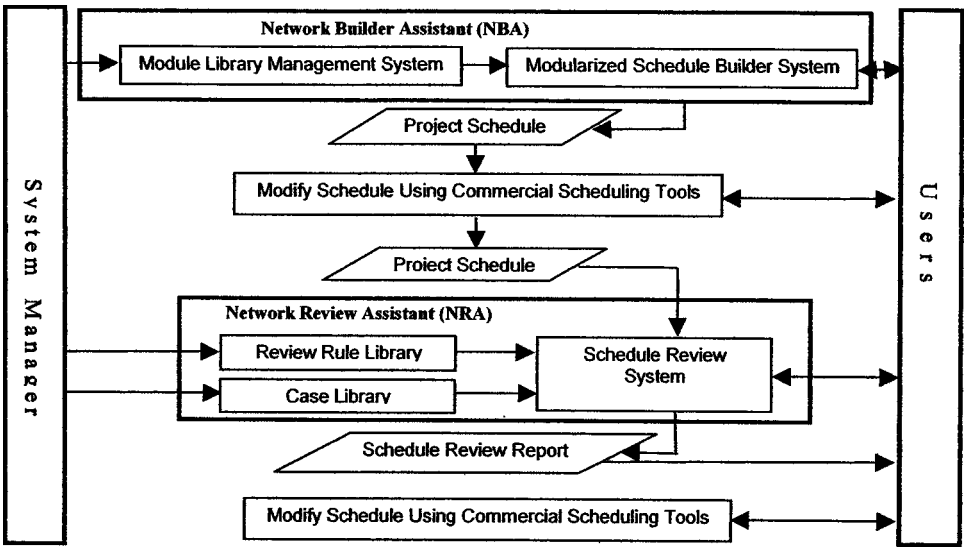

Fig. 1. Framework for applications of network modules

outside the range (less than 1%). Reviewers may also adjust the thresholds by changing the allowed number of standard deviations of difference.

This section has described the representation framework of NRA and how the integrated case-based reasoning and rule-based reasoning help human schedulers review an expressway construction schedule that is created from the developed modules. The next two sections describe the currently implemented applications of modules and their relationships, and the performance evaluation of NRA.

Applications of Modules

Fig. 1 summarizes the relationships of the current applications of network modules, NBA, and NRA. Arrows between boxes represent the primary direction of information flow. Readers may refer to Dzeng et al. (2004) for more details on the description of NBA's functions and performance evaluation.

The NRA was developed using *VBA* and *Access 2000*. It comprises three subsystems: review Rule Library (RRL), Case Library (CL), and Schedule Review System (SRS). The RRL allows the system manager to build new rules, edit, or delete existing rules. The CL allows the system manager to add new cases, edit, or delete existing cases. The SRS allows the user to read the schedule to be reviewed, set up the project basic information, and perform a review task.

The NRA currently can only read schedule data in database formats (i.e., *dBaseIV* and *MS Access* files). All of The *MS Project*, *OpenPlan*, and *P3* scheduling software allow users to export schedule files to such formats. The following steps describe basically how to use both rule-based and CBR of NRA to review a schedule.

1. Read the schedule data to be reviewed.
2. Input project basic information, and the associated weights for determining similarity in the CBR process (Fig. 2).
3. Deactivate the review rules that should be ignored by NRA (Fig. 3).
4. Determine the similarity threshold and NRA searches for similarity cases.
5. Remove the cases from the similar cases that should be ignored by NRA.
6. NRA starts the review process.
7. Visually inspect or print review results, including review of conformance to standard activities, review rules (Fig. 4), CBR calculation, and statistics of similar cases.
8. Visually inspect or print review items that were not reviewed by NRA.
9. Modify schedule data and determine if the reviewed project should be stored as a new case.

Evaluation of Network Review Assistant Performance

We evaluate the performance of NRA by comparing the review results of two test schedules generated by human reviewers and NRA. Two existing projects from TANEEB were selected for this evaluation. The schedulers who originally created the test schedules were asked to recreate the schedules using *P3* for the test scope of work so that they conform to the standard activity and codes. Schedulers are allowed to use nonstandard activities only when a part of the work cannot be described using standard ones. Four schedule reviewers (with 3–11 years of expressway construction experience) from TANEEB and its consulting firms participated in our test and performed the schedule review work.

The schedulers reviewed the schedules using *P3*. The review focused on finding any potential errors violating general expressway construction principles and TANEEB's general specifications, not conforming to the standard activity codes, and with irregular activity durations. These focuses are represented by "Rule," "Module," and "CBR," respectively, in Table 1, which shows the time spent and number of errors found by reviewers (RV) and NRA, respectively. Note that the time spent for the reviewers shown in the table includes the time required for recording the errors found, which accounts for about 15% of their time. The time spent for NRA includes the time for inputting the dialogs, but does not include the time for establishing the library of rules and cases. Also, the recorded number of errors found do not include those that NRA was not implemented to find such as

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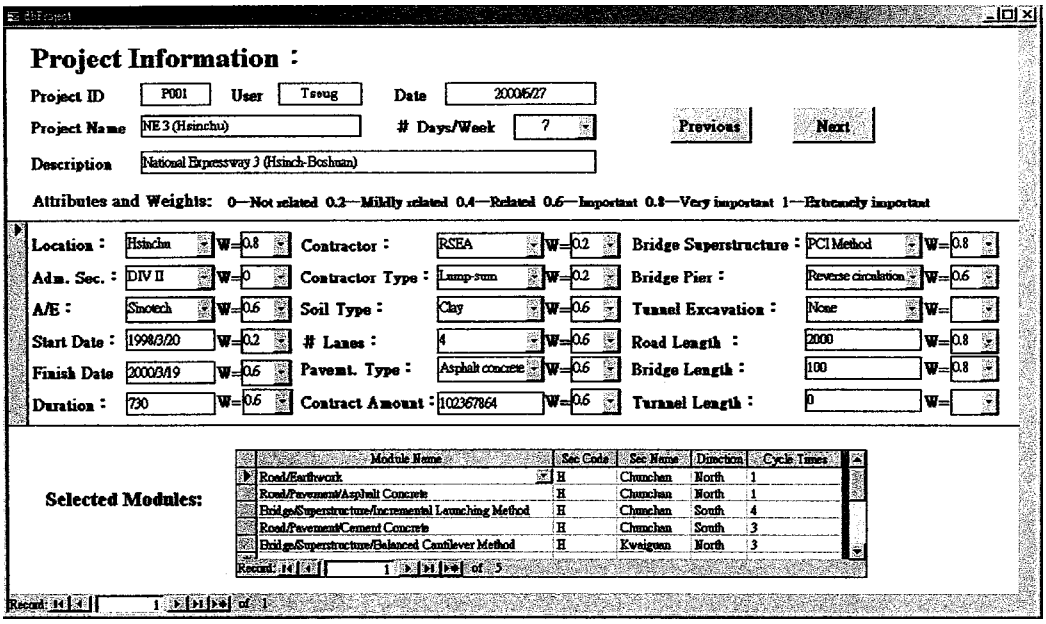

Fig. 2. Dialog for inputting project basic information

schedule format. The following summarizes the findings.

1. The time saving by using NRA increased as the number of activities in the test schedule increased. However, according to the reviewers, the number of cyclic activities alone in the schedule did not have a significant impact on the time saving. This may be because the schedulers used copy/paste functions for those cyclic activities—they were either all right or all wrong.
2. The numbers of errors found between the reviewers themselves, and between the reviewers and NRA were different. The additional errors found by NRA in "Module" were conclusive; i.e., NRA performed well on checking a schedule's conformance to the standard activities, which human reviewers often ignored. With respect to "Rule," the additional errors found by NRA belonged to the categories of "Important-But-Often-Omitted Activities." With respect to "CBR," the number of errors found by the reviewers and NRA was about 80% the same. The rest represented the review differences, most of which were subjective, experience-based judgment, and were inconclusive because we lacked much of the detailed resource information of the project. Such differences existed not only between the reviewers and NRA, but also among the reviewers themselves. The limited number of cases stored in NRA affected its judgment as the locations of the associated work experience of the reviewers affected theirs.
3. When the reviewers identified an error, they seldom made mistakes except for those in the "CBR" category where conclusive conclusions could not be reached. However, they might easily ignore some errors. This phenomenon was apparent when the number of activities involved was high, and especially in the "Module" category—a category where the review focused on how the work performed was represented (i.e., the conformance to the standards), not how the work was to be performed.

One function that has been implemented in NRA but not tested was the review of activities' pay items due to the large amount of input and review time involved. Other functions that may be implemented in the future include reviewing not only activity durations but also the durations in terms of modules and cycles based on CBR. For example, reviewers may like to know the average total duration of the "Balanced Cantilever Method" module for bridges with a similar length, or the module's average

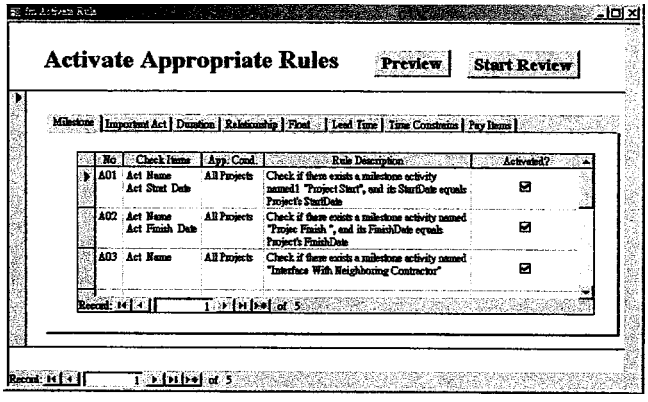

Fig. 3. Dialog for activating/deactivating rules

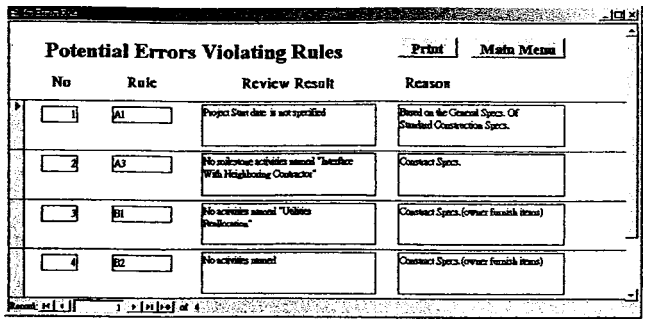

Fig. 4. Window for inspecting potential errors violating activated rules

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Table 1. Evaluation Results for Network Review Assistant (NRA)

				Time spent (minutes)					Number of errors found					
				Reviewer					Rule		Module		CBR	
Reviewer	Test project	Number of activities	Number of cyclic activities	Rule	Module	Case-based reasoning (CBR)	Total	NRA total	Reviewer	NRA	Reviewer	NRA	Reviewer	NRA
A	P1	54	12	25	60	10	95	8	3	3	6	7	6	4
B	P1	54	12	30	60	12	102	12	3	3	5	7	3	4
C	P2	368	86	120	200	45	365	16	10	12	15	26	16	13
D	P2	368	86	100	180	40	320	12	9	12	18	26	10	13

cycle time (i.e., from a "Box Girder Segment" activity to the next "Box Girder Segment" activity) for bridges with a similar span.

There are some limitations to this research. First, note that the amount of time spent recorded in Table 1 does not include the time for establishing the library of rules and cases, which exceeds significantly the total review time of any single project by human reviewers. Thus, developing such a system is only economical for an owner that builds repeatedly the same type of projects. Even with such an owner, the amount of time saved may also reduce if the owner has no standards for schedule review and each project requires significantly customizing the rules (i.e., activation/deactivation and change parameters). In addition, the knowledge and familiarity of the project gained by a human scheduler in reviewing a schedule may help resolve conflicts and manage the schedule. Such loss due to automated review has not been explored in this research.

Conclusion

Typical construction schedules for expressway projects contain hundreds of activities, each of which is associated with multiple pay items. With such a huge amount of information, the reviewer can only check a sample piece of information, and the quality of review highly depends on the reviewer's experience and devotion. This research proposes an automatic review system called NRA, which helps practitioners review schedules. To experienced reviewers, NRA improves their work efficiency. To inexperienced or careless reviewers, NRA helps maintain a certain level of review quality. Automatic reviewing schedules from the owner's perspective based on the integration of the modules, rule-based reasoning, and case-based reasoning is also an innovative approach that has not been found in the research literature of the schedule review.

This research has addressed not only the automation issues but also the standardization issues. The inclusion of NBA in addition to NRA in the proposed model provides standardization incentives for schedulers, who are identified as the primary barrier for activity standardization. The modeling of activity behaviors (i.e., normal, cyclic, and merging) allows schedulers to reuse the modules more efficiently. The research also surveyed the schedule review practices from the perspective of a public agency for the expressway construction. Common review items have been identified, and their feasibilities for automated review have also been studied. Those review items suitable for automation have been implemented in NRA based on the rule-based and case-based reasoning. The NRA has also been evaluated by comparing its review results against those of human reviewers. It performed well on checking the conformance of a schedule to the standard activities and owner's specified general scheduling principles, and finding important but often omitted activities. The NRA's review of activity durations were inconclusive due to the lack of information about the project resource usage, which could have been implemented but the required large amount of additional data input might make the application impractical. The research also found human reviewers seldom made mistakes when they identified errors. However, they often ignored some mistakes, especially when a large number of activities were involved. This has given NRA a position to help reviewers because it may occasionally generate false alarms (e.g., when reviewing pay items) but seldom missed potential errors when the review of those items were implemented.

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Appendix. Sample of Schedule Review Activities

Category	Review description	Application	Examples of errors found	Feasibility study of automated review	Feasible?	Recommended
			Schedule level			
Format (10)	Check if the node representation includes required information.	All	The node did not include information about floats.	The inclusion of early, late, planned, or actual times, and total and free floats could be verified automatically.	Yes	Yes
Activity (3)	Locate nonstandard activities.	All	Work that could have been represented by standard activities was represented by nonstandard ones.	The checked items were specific and it took time for reviewers to find the activities among many.	Yes	Yes
Milestone (8)	Check if "Notice to Proceed" activity exists, and ensure its dates match contract specifications.	All	Forgot to add the activity. The dates did not match the contract specs.	The checked items were specific (assuming the activity names are standardized) and it took time for reviewers to find the activity among many.	Yes	Yes
Important but often omitted activities (12)	Check if "Land Acquisition" activity exists.	All	Forgot to add the activity.	The checked items were specific (assuming the activity names are standardized) and it took time for reviewers to find the activity among many.	Yes	Yes
Critical paths (3)	Check if layout of critical activities is reasonable.	All	Some activities became critical because of imposed inappropriate constraints.	Reasonable critical paths varied by project. Much input was required to determine if paths were reasonable, thus was better off checked by reviewers	Yes	No
Working calendar (2)	Check if project time is correctly calculated.	All	Project time was not calculated based on the method specified by the contract.	The checked items were specific (i.e., work day, calendar day, holidays) and it took time for reviewers to locate holidays.	Yes	Yes
Work interfaces (1)	Check if arrangement of shared equipment and its quantities match scheduled progress.	All		The problem was complicated and much of required information was not in the schedule.	No	No
			Activity level			
Activity duration (2)	Check if durations of standard activities are reasonable.	All	Activities had durations greatly deviated from the averages in the past.	Activity durations were currently reviewed subjectively and often omitted in a large schedule. Collection and comparison of activity durations against corresponding statistics could be easily automated for standard activities.	Yes	Yes
Activity relationships (3)	Avoid open-end activities.	All	Forgot to add required relationships	Most scheduling tools (e.g., *filter* in P3) were able to screen out such activities.	Yes	No
Activity float (1)	Check if activities with overlong floats are reasonable.	All	Activities had unreasonably large floats because of missing relationships with successors.	Most scheduling tools (e.g., *filter* in P3) were able to screen out such constraints.	Yes	No
Time constraint (3)	Check if imposed time constraints are necessary and appropriate.	All	Unnecessary constraints were imposed to achieve specified project completion date, change the critical paths, or reduce activity floats.	Most scheduling tools (e.g., *filter* in P3) were able to list such constraints for review. Much input was required to determine if they were reasonable, thus was better off checked by reviewers.	Yes	No
Lead time (3)	200 days of self-settlement for road embankment is needed after it is finished.	Civil work	Reserved self-settlement time was not enough.	The checked items were specific and it took time for reviewers to locate the activities among many.	Yes	Yes
			Meta-activity level			
Pay item (2)	Check if standard pay items are associated with appropriate activities.	All	Associate activities with inappropriate pay items.	The checked items were specific and it took time for reviewers to locate the activities among many.	Yes	Yes
Resource (1)	Check if quantities of resources available match scheduled progress.	All	The schedule of a project using advancing shoring method showed a progress based on six wagons while the contractor had only four.	The checked items were specific. However, current schedules did not adopt any code standard for equipment, and the owner was only interested in critical equipment (e.g., wagon).	Yes	No

References

Ahuja, H. N., Dozzi, S. P., and Abourizk, S. M. (1994). *Project management: techniques in planning and controlling construction projects*, Wiley, New York.

De La Garza, J. M., and Ibbs, C. W. (1990). "Knowledge-elicitation study in construction scheduling domain." *J. Comput. Civ. Eng.*, 4(2), 135–153.

Dzeng, R. J. (2000). "Development of activity network modules for expressway projects." Tech. Rep., Taiwan Area National Expressway Engineering Bureau, Taipei, Taiwan (in Chinese).

Dzeng, R. J., and Tommelein, I. D. (1997). "Boiler erection scheduling using product models and case-based reasoning." *J. Constr. Eng. Manage.*, 123(3), 338–347.

Dzeng, R. J., and Wang, W. C. (2003) "Automatic schedule integration for highway projects." *Autom. Constr.*, 12(4), 447–461.

Dzeng, R. J., Wang, W. C., and Tserng, H. P. (2004). "Module-based construction schedule administration for public infrastructure agencies." *J. Constr. Eng. Manage.*, 130(1), 5–14.

Primavera Systems, Inc. (1999). *Primavera Project Planner 3.0 Reference Manual*, Bala Cynwyd, Pa.

Shaked, O., and Warszawski, A. (1995). "Knowledge-based system for construction planning of high-rise buildings." *J. Constr. Eng. Manage.*, 121(2), 172–182.

Zozaya-Gorostiza, C., Hendrickson, C., and Rehak, D. R. (1989). *Knowledge-based process planning for construction and manufacturing*, Academic, Boston.

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