Application of a Agent Mechanism to the Small-Scale Maintenance of School Buildings

Chih-Yuan Chang, Dept. of Civil Engineering, National Taiwan University, Taiwan.
（f90521705@ntu.edu.tw）
Yuan-Chu Chang, Graduate Institute of Information Management, Chinese Culture University, Taiwan.
（g9214003@ms2.pccu.edu.tw）
Shyh-Meng Huang, Dept. of Civil Engineering, National Taiwan University, Taiwan.
（smhuang@ccms.ntu.edu.tw）

Summary
This paper presents an agent-based software, Virtual Administrator System (VAS) for the small-scale maintenance of school buildings. VAS is capable of handling a heavy load of routine, low-tech maintenance jobs. It assigns a different priority to each job application according to its significance and urgency, and automatically adjusts schedules for maintenance engineers when on-site supervision is needed. The system can help ease off the burden of routine small-scale maintenance work, making it more cost-effective and efficient in the overall management of school building maintenance.

VAS posts jobs on the Web in a multi-media format and classified all applications into four categories: the on-call maintenance contract, the term maintenance contract, the guaranty maintenance contract, and the regular maintenance contract. It then estimates their urgency level and passes the information to maintenance engineers who will decide whether on-site inspection is needed. Based on the engineers' feedback, VAS automatically implements the scheduling for inspection as well as sends out real-time or batch notifications to contractors. All these activities are recorded in a database to allow continuous research and data mining and the analysis and diagnosis of specific jobs for followup maintenance plans.

1 Introduction
School buildings make up not only the largest group of public buildings in Taiwan, but also the fundamental hardware to the development of the nation's education. As expected, routine maintenance jobs play a key role in keeping this hardware function properly. Nevertheless, with limited resources, how to deliver quality maintenance of these buildings to the taxpayer is becoming a challenge for school administrators facing an increasing demand for maintenance jobs. This study explores ways for the school to take advantage of Information Technology to correct problems resulting from inadequate human resources for routine maintenance jobs.

Quality maintenance of a building is essential to its extended serviceability especially in the later phases of a building's life cycle. The maintenance of public buildings is as important to public safety as it is to assets management. In the past, both public and private organizations focused on the design and construction phase of their buildings and tended to neglect long-term maintenance needs. Besides this customary shortsightedness, a dwindling government budget in recent years only served to aggravate the situation. Today, most public schools suffer from a small maintenance budget and a lack of maintenance hands. While Information Technology may not be able to solve the budget program, it will provide the management with a powerful alternative to deal with the shortage of manpower. In this research, we will establish a procedure of applying software agents to coordinate and expedite the numerous routine small-scale maintenance jobs. This model not only reduces the routine workload for maintenance officers, but also prevents the indirect shift of inspection cost to the school.

2 Current Maintenance Management in Schools

In 2003, there were 8222 schools in an area of approximately 36000 square kilometers in Taiwan [1], or roughly 228 schools per thousand square kilometers. This dense population of schools, public and private, translates into a huge amount of maintenance work. In general, the more established a school is, the more buildings it has to maintain, hence the greater need for a bigger budget and more manpower. Although each school has its own maintenance department, the general lack of human resources and professional skills is common; routine maintenance work is usually done with low efficiency. Most schools are completely unaware of the role information technology can play in implementing building maintenance.

2.1 Human Resources and Small-scale Maintenance Applications

Virtually every school in Taiwan faces a dwindling of maintenance budget and a shortage of skilled workers. For example, in the local high schools, the General Affairs Department that oversees building maintenance is usually understaffed. Individuals who are in charge of implementing scheduled maintenance are appointed from the general faculty with little or no professional training in civil engineering, architectural engineering, or water or electricity engineering. [2] In the public universities, the situation is different. Individuals with maintenance-related skills and knowledge are chosen to head the Construction and Maintenance Departments whose staff usually have to pass a national examination for public employment and are tested in professional skills and knowledge. The same cannot be said about some private universities, where the quantity and quality of the maintenance crew are sometimes open to question. And while the training of the maintenance crew is seldom a serious problem in the universities, the insufficient number of skilled people assigned to do building maintenance jobs does pose some problems.

Take National Taiwan University (NTU) as an example. Founded in 1928, NTU is the oldest university in Taiwan boasting a 110-hectare campus littered with 1138 buildings and a 2002 maintenance budget of NT$ 96,607,640. There are 10 employees in charge of building maintenance, four of whom are full-time maintenance engineers with professional background in civil engineering and architectural engineering. These four oversee all construction and building maintenance works, while the other six are part-time employees and fire marshals assigned to regular water and electrical maintenance jobs. This breaks down to a staggering 284 buildings per civil engineer and 190 buildings per water and electrical engineer. In the fiscal year 2000-2001, a total of 4542 applications for small-scale maintenance were requested. The ratio of small-scale maintenance to all maintenance jobs was approximately 97:100, yet the ratio of small-scale maintenance expenses to the entire maintenance budget was a paltry 36:100[3]. In 2002, there were 2121 small-scale maintenance requests, and while the ratio of small-scale maintenance to all maintenance cases held steady at 96:100, the ratio of expenses dropped to less than 26:100 (cf. Table 1). Assuming that the crew of 10 was supposed to handle all the requests from 2000 to 2002, each would be assigned 452 cases per year. Based on a 275-working day calendar year, each engineer would need to complete 1.64 applications every working day.

Table 1 highlights the heavy load of small-scale maintenance applications at NTU. The discrepancy between a high ratio of small-scale applications and a low ratio of small-scale maintenance expenditure is causing serious problems in building maintenance. The situation is worse in elementary schools, junior high schools, and senior high schools across Taiwan where an absence of a skilled maintenance crew adds to the already difficult situation.

Table 1 Analysis of maintenance applications in NTU from 2000 to 2002.

Items \ Fiscal Year	2000-2001	2002
Number of Applications	4677	2212
Sum of Expenditure	NT $ 232,530,000	NT $ 96,607,640
Number of Small-Scale Applications	4542	2121
Sum of Small-Scale Expenditure	NT $ 83,750,000	NT $ 25,308,181
Ratio of Small-Scale Applications	97.11%	95.89%
Ratio of Small-Scale Expenditure	36.02%	26.20%

Remarks: 1. Campus area：1266607 m^2
2. Total building floor：853231m^2
3. Number of buildings：1138
4. Maintenance crew：Four full-time administrators for construction and six part-time administrators for water and electricity maintenance.

2.2 Maintenance Contracts

Currently, there are four major types of maintenance contracts used by schools, namely, the on-call maintenance contract, the term maintenance contract, the regular maintenance contract, and the guaranty maintenance contract.

The on-call maintenance contract covers four general areas of small-scale maintenance jobs on a fixed price basis. These areas include ground construction, building maintenance, water and electricity systems, and maintenance of communication equipment. When a job specified on the contract is in order, the Construction and Maintenance Department of the school notifies the contractor to come and do the necessary repair and maintenance. When the number of jobs performed and the amount of money paid to the contractor reach 95% of the capacity specified on the contract, the contract will be ready for a closure. The on-call maintenance contract eliminates the need to frequently invite bids for small-scale maintenance jobs. More and more schools in Taiwan are relying on this kind of contract.

The term maintenance contract is an annual contract covering water and electricity maintenance and repair, such as cooling tower cleaning, elevator and drinking fountain inspection and maintenance.

The general maintenance contract is sought only when a specific and usually more costly maintenance job is requested that is not listed either in the on-call maintenance or in the term maintenance contracts. The school initiates a formal bidding according to the Government Procurement Law before signing the contract with the winner.

The guaranty maintenance contract is a fixed-term contract covering contract-specified repair and maintenance costs for newly-built school buildings.

3 Problem Description and Research Objectives

Small-scale maintenance is defined as any single maintenance engineering with a net value under NT$100,000. It covers low-cost repair and maintenance of a non-dispute nature in the following categories: ground construction, general building maintenance, water and electricity systems, and communication equipment maintenance. Small-scale maintenance items regularly account for a predominant part of the on-call maintenance contract (cf. Table 2).

Figure 1 shows the implementation chart of the four maintenance contracts, of which the guaranty and term maintenance categories do not require separate bidding for covered jobs. Invitation for public bids for general maintenance items, however, has to be posted for at least

14 days before a constract is awarded, and the time between the tendering of bids and the carrying out of the actual maintenance is usually a month. Article 28 of the Government Procurement Law stipulates, “for open tendering procedures or selective tendering procedures, an entity shall prescribe a reasonable time-limit for submission of tenders, which shall not be less than 14 days for tendering from the date of publishing a notice or of invitation to tender. Within the prescribed time-limit, the notice shall also be continuously posted on the entrance of the entity.”[4]

On-call contracts, on the other hand, can save a tremendous amount of time and are clearly more efficient than general maintenance contracts (cf. Figure 1). Most maintenance requests covered by on-call contracts are executed in a week, or even in a single day.

Table2. Examples of on-call maintenance contracts

Types of Maintenance Items	Ground Construction	General Building Maintenance	Water and Electricity	Communication Equipment
Maintenance Items	Asphalting and digging, road marking, gutter covering, etc.	Ground brick digging and covering, shingle waterproofing, floor and wall covering, aluminum doors and windows, etc.	PVC pipe replacement, electric wires, NFB replacement, lamps and lanterns, stools, hydrants, washbasins, etc.	Telephone lines

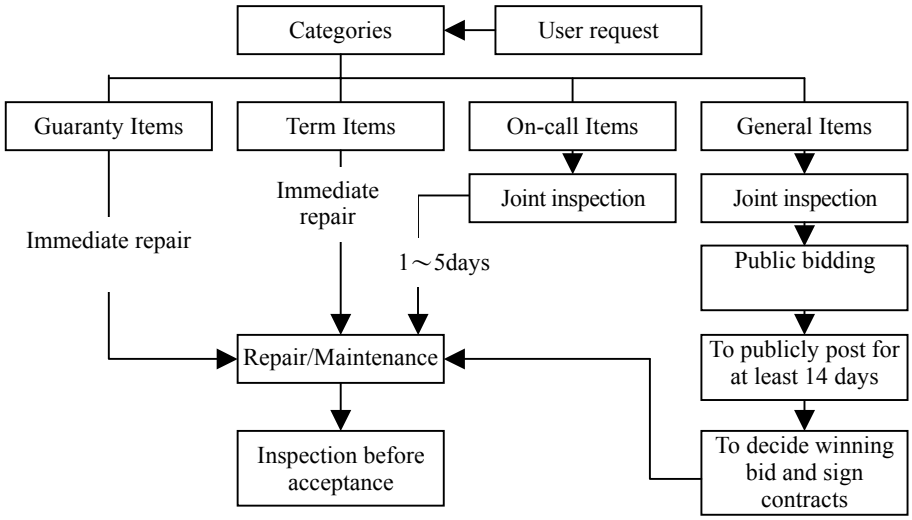

Figure1. Implementation chart of school building maintenance in colleges / universities

The large volume of small-scale maintenance requests that regularly floods the Maintenance Department means that the actual implementation process may be somewhat different for on-call items. Because of the lack of manpower, the Maintenance Department often asks the contractor to do an on-site inspection first and report the number of jobs and the total maintenance cost back to the Department. The Department then seeks authorization from the school authorities for the maintenance jobs. This shortage of manpower also means that maintenance administrators sometimes conduct only part of the on-site inspection by themselves or authorize jobs covered by on-call contracts without any prior inspection at all. In the worst-case scenario, when a large volume of small-scale maintenance requests threatens to disrupt regularly scheduled maintenance, the following serious problems may occur:

1) Inexact evaluation.
2) Additional on-site inspection cost charged to the school. (Inspection should be done by school maintenance administrators without incurring additional fees.)

3) Overstretched maintenance resources cripple large-scale maintenance works and render inefficient other regular maintenance works.
4) Risky delay of necessary maintenance.
5) Inappropriate record-keeping.

The VAS, an agent-based system can help the maintenance crew evaluate and filter small-scale job applications, set on-site inspection and maintenance schedules, as well as notify contractors for maintenance works and monitor their progress. It significantly reduces the workload of maintenance administrators and the need for contractors to conduct on-site inspection at the school's expense. This could mean more efficient management of small-scale maintenance jobs and fewer risky delays of necessary repairs. The system maintains a database of all job records to facilitate future maintenance planning and research.

4 Framework of VAS

4.1 Agent-oriented programming

In recent years, agent-oriented programming, also called software agents, has been widely used to help people manage their daily routines in such areas as workflow management, web-information search, e-commerce, task and scheduling management, and e-mail filtering. While researchers have yet to agree on a final definition of agent-orient programming, software agents do share some common characteristics:

Software agents are task-oriented. They can carry out fixed tasks continually and autonomously with minimum human intervention. They make certain decisions for us, thus reducing our workload and leaving us with more precious time to manage complicated tasks and make more difficult decisions.

From the user's point of view, a software agent is a virtual sidekick or the user's double assigned to accomplish a certain task. As part of the system, software agents are autonomous, task-specific, context-sensitive programs that continually execute certain routines. They have built-in communication and learning capabilities, as well as a strong mobility and a high degree of reliability.

Short of debating the ideas of agent-oriented programming, this study takes advantage of software agents to find solutions for actual problems in school building maintenance.

Software agents can be classified into four types: [5]

1) Robotic agents: hardware or software that functions autonomously in a physical environment.
2) Softbots: software systems that are able to perform tasks by synthesizing their behavior in software environments.
3) Personal assistants: software agents that continuously interacts with the user in performing such tasks as decision making, information gathering, daily routines, etc.
4) Synthetic or believable agents: agents operating in artificial environments such as interactive games or virtual space.

VAS is designed as a personal assistant to help school administrators handle routine maintenance tasks more efficiently and to lower the cost of school building maintenance.

4.2 Application of VAS

In the following we will discuss the growing need for colleges and universities to implement a software system with distributed tracking capability and design as an intelligent solution to small-scale maintenance management.

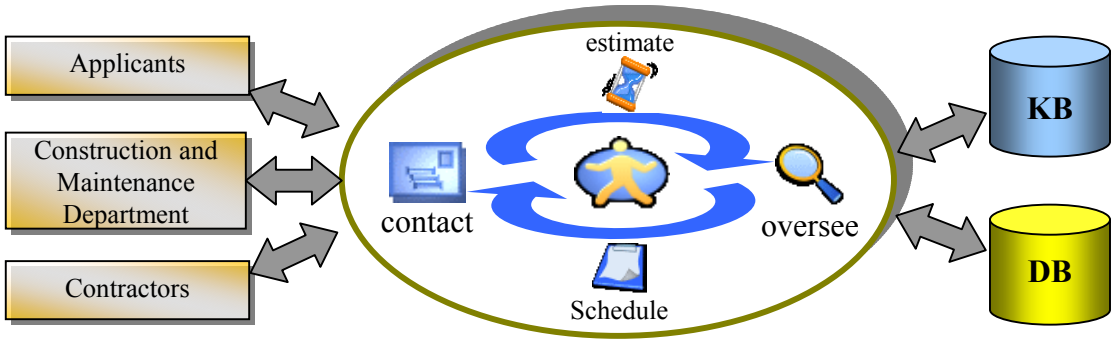

Figure2. Concepts of VAS Framework

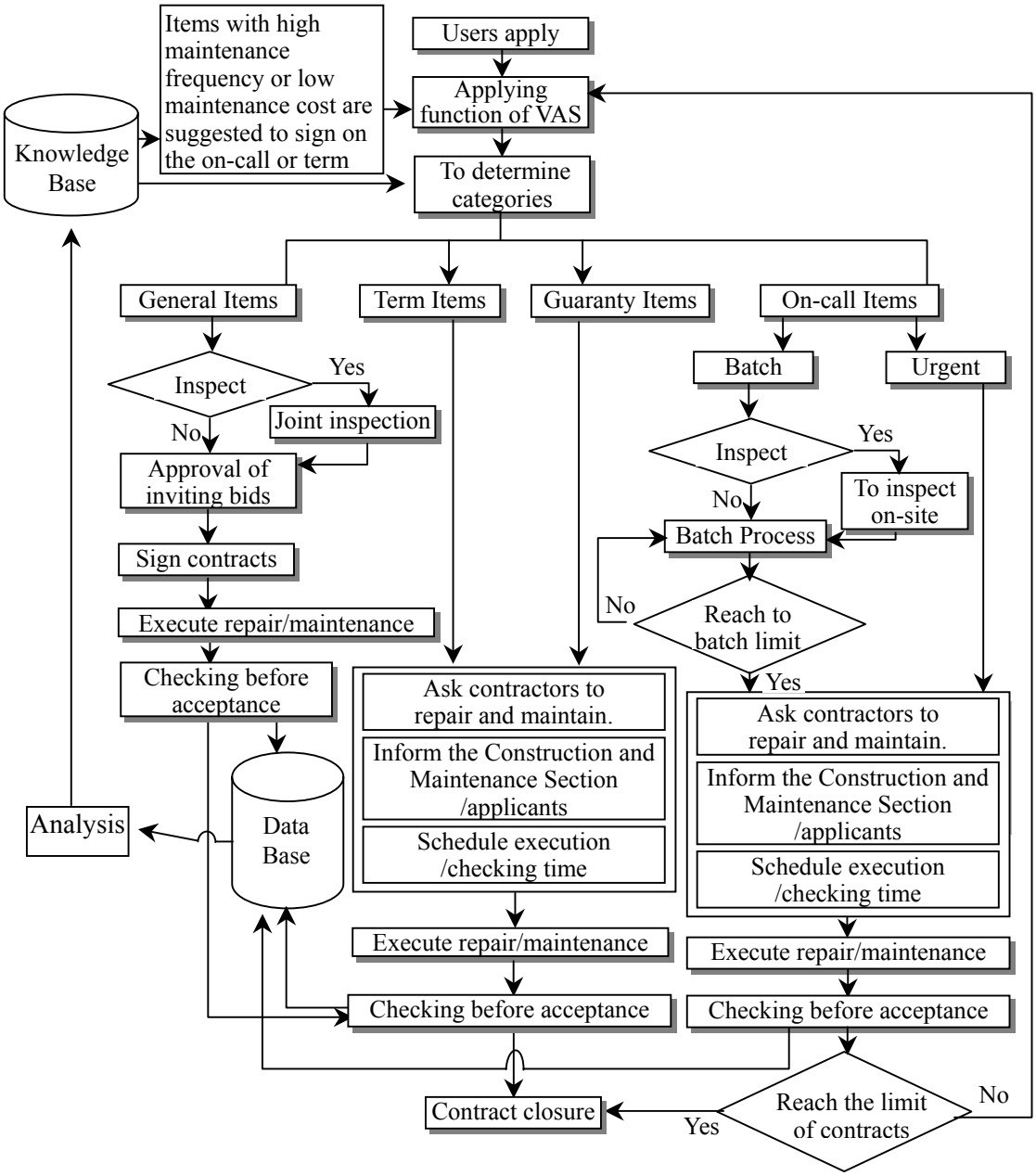

Figure3. The procedure of school building maintenance in colleges/universities

Figure3 illustrates a VAS-controlled maintenance process.

Although the General Affairs Department of a school is principally in charge of school building maintenance, engineers do small-scale maintenance work in many separate locations. A distributed system allows administrators to manage maintenance jobs from a single platform. In order to facilitate the integration of VAS on existing systems, we use Object-Oriented Programming in JAVA and JSP to build a VAS framework and customize an XML for easy data exchange. [6] The VAS system is also capable of handling multimedia attachments, giving engineers a chance to preview the damage and decide if on-site inspection is needed. Figure 2 shows the main skeleton of the VAS framework.

4.3 Main Functions of VAS

The VAS is mainly designed for colleges and universities with sizable facilities including large-scale buildings. It helps school administrators manage the maintenance of these buildings and their facilities such as water and electricity systems, air conditioners, fire-fighting equipment, etc. There are three major groups of VAS users, namely, the contractor, the school building user, and the maintenance engineer. All of them have access to and can interact with VAS through the Web-based user interface of the distributed systems. VAS will reduce the workload of school maintenance administrators and cut down shift-costs via the concerted effort of three fundamental functions: preliminary estimation, task scheduling, and continuous oversight.

4.3.1 Estimation

When a request for maintenance is submitted, the system will filter the request through existing lists of jobs for the on-call maintenance contract and the term maintenance contract before assigning it one of the four types of maintenance contracts. Different jobs follow different procedures as illustrated below:

A. On-call Maintenance Contracts：

The on-call maintenance contract covers ground construction, general building maintenance, maintenance of water and electricity systems, and communication equipment maintenance (cf. Table 2). The contract is signed with a net value agreed on by both sides. When an on-call maintenance item becomes urgent, the VAS system will notify the contractor for immediate service via any of the following communication channels: fax, e-mail, voicemail, or mobile phone message. The system will automatically notify the maintenance administrator and the party requesting the service.

To minimize unnecessary maintenance, the system incorporates automatic batch processing to prioritize non-urgent service items. Only when a regular request meets any of the three principles below will the system notify the contractor for maintenance.

1) The accumulated value of the maintenance request exceeds NT$30,000.
2) The number of requests for the same item exceeds three.
3) Any other requests that are a week old.

Note that all the parameters in the three principles above can be adjusted based on actual conditions and the maintenance needs of the school. In an urgent situation, the principles can be sidestepped altogether. Maintenance administrators can set their own criteria for urgent repair by assessing how serious the consequences will be, whether essential school operations will be halted, and if any human lives will be jeopardized if the maintenance is delayed. Administrators can also authorize emergency repair based on the recommendations of their maintenance engineers.

Excessive requests for service often force the small-scale maintenance contractor to shift some

of the financial burden to the school. A batch processing routine effectively prevents such abuse of maintenance resources by filtering the requests, thus lowering the possibility of indirect cost shifts.

B. Term Maintenance Contracts：

The term maintenance contract covers mechanical and electrical items. The VAS system will confirm each request by matching it against the list of jobs written for the term contract, and check to see if a particular school building where service is requested is covered. For instance, elevator maintenance is a broad item under the term maintenance contract, but it doesn't mean that every elevator on campus is covered. Any mechanical or electrical item not listed on the term contract will be re-assigned to regular maintenance. If VAS determines that a maintenance job belongs to the term maintenance contract, the system automatically notifies the contractor for immediate service. It will also notify the maintenance administrator and the party requesting the service.

C. Guaranty Maintenance Contracts：

The guaranty maintenance contract covers new school facilities for a fixed term. Items on the guaranty contract will be treated in the same way as those on the on-call maintenance contract minus the batch processing routine. VAS will immediately notify the contractor for service.

D. Regular Maintenance Contracts：

When a request cannot be assigned to any of the above contracts, it belongs to the regular maintenance contract and must be handled according to the Government Procurement Law.

4.3.2 Maintenance Scheduling

VAS allows applicants to write in their preferred schedule for the maintenance, but the system screens the requests to separate the urgent ones. VAS will notify the contractor in case of urgent repair and ask the contractor to schedule the repair on the VAS scheduling interface. It will then notify the applicant and the maintenance administrator of the maintenance schedule right away. If VAS decides that an item is not urgent, it will route the request through the batch routine, and the contractor will then schedule the maintenance around the preferred time indicated by the applicant. After a schedule is set, the system will notify the applicant and the maintenance administrators by e-mail.

In addition, VAS can assists maintenance administrators to organize their work schedule, plan meetings and business trips, keep track of days off, and, above all, schedule on-site inspections.

VAS will batch-process requests and forward any multimedia attachments to maintenance administrators who will be able to assess the condition on screen and decide if a site visit by the administrators themselves is needed or if the contractor should be invited to conduct a joint inspection. Once an inspection schedule is keyed in, the system will rearrange the work schedule for the administrators and notify the contractor and the applicant of the inspection time. During the site inspection, all parties can agree on a time for the maintenance work to be carried out. This time will then be keyed into the scheduling interface of the system, which will notify the contractor of the repair.

Batch-processed maintenance jobs that do not require site inspection will be coordinated by the applicant and the contractor. After a repair schedule is set, the contractor enters the information into the VAS system. The system then notifies the maintenance administrator of the time of the maintenance to arrange for a post-repair quality inspection to expedite the case closure procedure. Figure 4 shows the complex process of maintenance scheduling.

Because of program constraints and user preferences, scheduling solutions are bound to be constraint-satisfying solutions. Constraint solution problems (CSP) can be solved using a modified CSP algorithm based on the A*-search concept. [7]

Because the three elements of the maintenance, namely, the inspection, the repair, and the

follow-up quality check, are to some extent constrained by the nature of the repair and the degree of urgency, and not the least by the scheduling preferences of the parties involved, the resulting solution is bound to be a constraint-satisfying solution and is treated as a constraint solution problem in this research.

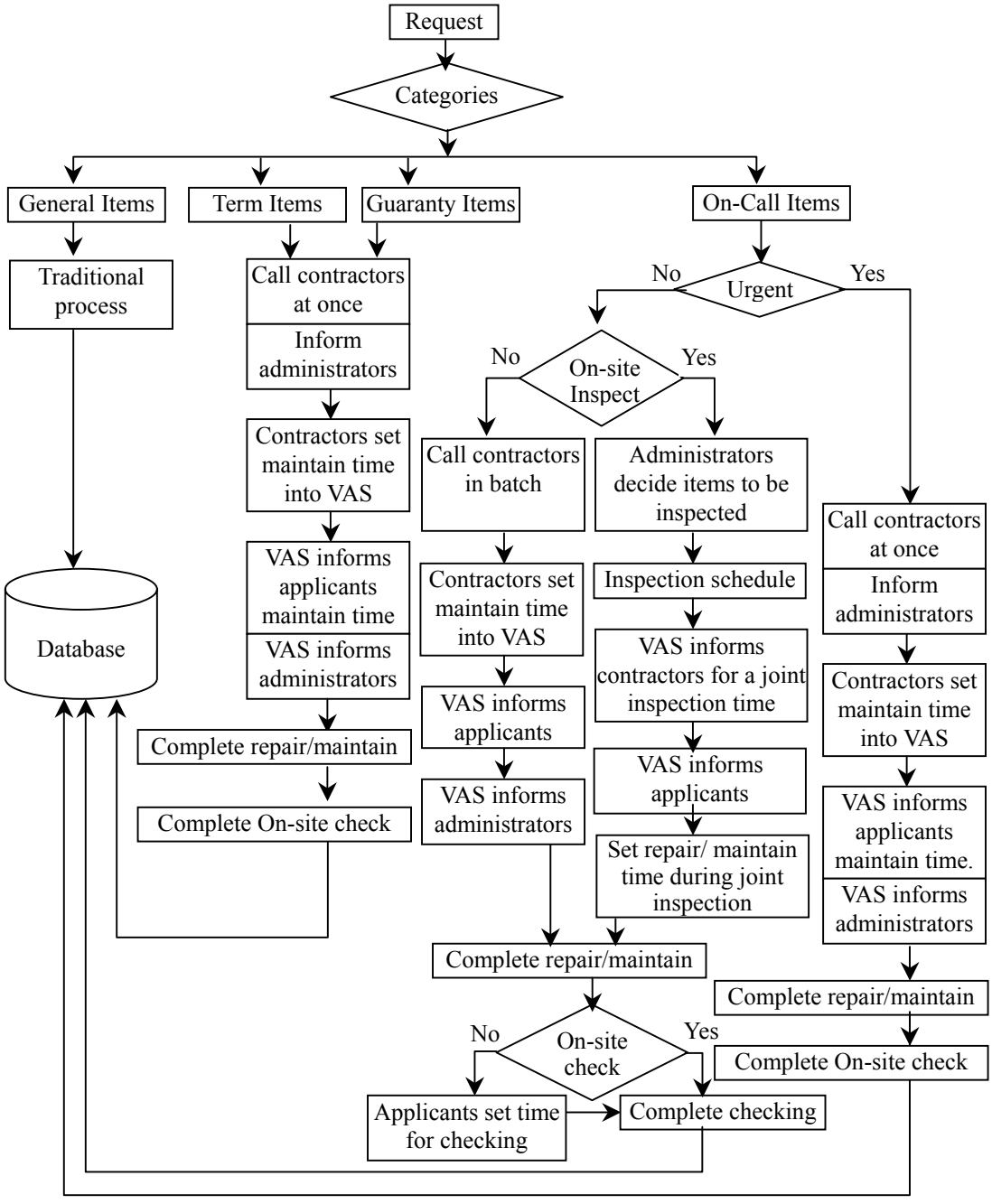

Figure4. Notification Procedure

We propose in the following a set of guidelines for scheduling maintenance jobs based on the improved learning algorithm by Lin [7]:

1) Sort the maintenance job. Is it urgent? Or is it a batch job?
2) Define the nature of the maintenance job. Is it a site-inspection, a regular repair, or is it a quality acceptance check?

3) Analyze the hard and the soft constraints of each maintenance job. Hard constraints include absolute priority, forbidden job, and permitted job. Soft constraints are degrees of preference.
4) Resolve the possible conflicts and interferences of two or more jobs, including precedence restrictions, precedence preferences, time margin restrictions, and time margin preferences.

Based on the order of the above guidelines, the system will determine and record the attributes of each maintenance activity and schedule the absolute-priority items first. Next, the system will close the time slots with a hard constraint value of "time not allowed." It then calculates the preference values of the applicant, the contractor, and the administrator to find the most sought after time slot and schedules the maintenance accordingly. The time slot with the highest positive preference value will be dropped, however, if it is associated with a higher negative preference value. The system will then compute again to find the time slot with the next highest preference value.

In addition, the system uses a decision tree induction algorithm to integrate user scheduling models and further enhances its learning ability with the HID3 algorithm refined from the ID3 family of algorithms. Thereafter the system automatically suggests user constraints and preferences when a new activity is scheduled. [7] Thus the system expedites task scheduling for maintenance administrators and reduces their contact time with the applicant and the contractor.

4.3.3 Maintenance Oversight

VAS monitors the process of each repair or maintenance and records all information in the system. It picks out service items that cost under NT$100,000 as well as items whose annual maintenance frequency is higher than 1%. Once or twice every year the system issues a recommendation to maintenance administrators to reassign these jobs to the on-call contract or the term contract to scale down the number of items on the general maintenance contract, hence a reduced workload for the administrators. The annual maintenance frequency rate is calculated using the following formula:

Annual frequency = (number of services for a particular item per year / total number of all maintenance items per year)

When necessary, maintenance administrators can adjust the parameters of the formula.

5 Conclusion and Suggestion

Our research proposed a VAS framework to implement cost-saving measures and solve the problem of lack of manpower in the small-scale maintenance of school buildings. When a request for maintenance is entered into the system, VAS automatically screens the request against contract stipulations to determine the category of the service item and schedules the maintenance accordingly. Once an item is scheduled, the system sends a notice to all parties to confirm the dates and times of the site inspection, the repair and maintenance, and the quality acceptance check. This results in a tremendous saving of time for maintenance administrators who otherwise must contact all the parties themselves for every single repair. As an agent-based system, VAS oversees the workflow, monitors the process, and records the information in its database, much like a human administrator. It then analyzes the data to identify items that may be misclassified. VAS will monitor these items and issue recommendations to maintenance administrators to reassign them to more accurate and appropriate contracts.

This research reaches into the untapped resources of applying software agents in the maintenance field. Possibilities exist for a more intelligent, fuzzy-controlled VAS that supports

sophisticated calendar scheduling and expedites decision making with its enlarged knowledge base of maintenance-related data and an enhanced multimedia object base for data retrieval and analysis.

The autonomous and continuous operation of VAS means the number of small-scaled routine maintenance works will decrease, freeing the otherwise overloaded administrators of the Construction and Maintenance Department to handle more costly major repairs. Meanwhile, the shift cost is prevented and the overall cost for school building maintenance goes down. Administrative resources can then be distributed more appropriately. In short, software agent mechanism can help school administrators to repair and maintain their facilities more efficiently and more economically.

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