# Demonstration of Software Agents Prototype System: [AIMM] Agents for Improving Maintenance Management

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# 1. SUMMARY

This report presents the demonstration of software agents prototype system for improving maintenance management [AIMM] including:

- Developing and implementing a user focused approach for mining the maintenance data of buildings.
- Refining the development of a multi agent system for data mining in virtual environments (Active Worlds) by developing and implementing a filtering agent on the results obtained from applying data mining techniques on the maintenance data.
- Integrating the filtering agent within the multi agents system in an interactive networked multi-user 3D virtual environment.
- Populating maintenance data and discovering new rules of knowledge.

# 2. A USER FOCUSED APPROACH FOR MINING MAINTENANCE DATA OF BUILDINGS

*"All truths are easy to understand once they are discovered; the point is to discover them."*

Galileo Galilei

The management of building facilities is essential to achieve better reliability and availability of the equipment installed. It is important to minimise downtime of all equipment that is used as the downtime will impact on the usability and profitability of the building itself. Maintenance activity, as part of a business process within an internal organisation, contributes to the successful operation of the physical asset. The maintenance budget is a significant cost and thus very important for the overall economic results. The problem with maintenance, from a business point of view, is that the costs are easily measured, while its contributions to the company's revenues are not directly obvious. A cut in maintenance funds can lead to problems with the performance of the surface facilities and this can become very expensive for the whole of the ongoing business process.

Most currently available computer tools for the building industry offer little more than productivity improvement in the transmission of graphical drawings and textual specifications, without addressing more fundamental changes in building life-cycle modelling and management. This concept has been founded a software agents prototype system developed, implemented and integrated in an interactive networked 3D virtual environment that promotes multiple participant involvement and models building life-cycle information with a product model of the physical design of that building. Figure 2.1 shows the interface of the software prototype system (AIMM, Agents for Improving Maintenance Management) in an interactive networked multi-user environment (Active Worlds). The data currently represents level 6 of building no. 10 at the Royal Prince Alfred Hospital in Sydney. The prototype system can be accessed from anywhere in the world by different users simultaneously while users will be aware of the presence of others within the same environment. They may choose to conduct a meeting, leaving a note to others, etc. Each user may use the prototype system to mine the maintenance data based on his/her focus and interest. Each user might be looking at different building assets and using different mining or discovery techniques than others within the same environment while talking to each others synchronously. Each user can be represented by an Avatar within the environments as shown in Figure 2.2. Users may choose different shapes and forms of Avatars to present themselves. Users can have access to the prototype system by installing the client software of the network multi-user virtual environments (Active Worlds) at their own computers and access the server remotely whereas the prototype system should be available at their computers.

The prototype system [AIMM] utilises data mining techniques to discover rules and patterns of useful knowledge from the maintenance records of a building to help improve the maintenance management of existing and future buildings. Data mining may be thought of as Knowledge Management. Data mining resembles a statistical method but differs in its purpose. The statistical method applies from data pre-processed to exclude any extraordinary data. On the other hand, data mining deals with all data, and has the capacity to find concealed patterns in the data. Data mining has been widely applied to mail-order businesses to find patterns of customer segmentation and customer purchase pattern analysis; retail traces such as shopping and basket analysis, merchandising effect measurement and laying-out change; maker and wholesale businesses such as optimizing of a delivery route, development of a new product and patent analysis; and finance such as portfolio management; Insurance such as detection a fraud; and Industry such as quality control, just to name a few of its many areas of application..

Data mining does not automatically extract all available knowledge that is embodied in a data set. Although it may sound at first appealing to have an autonomous data mining system, in practice, such a system would uncover an overwhelmingly large set of patterns, and most of the patterns discovered in the analysis would be irrelevant to the user. Therefore, it is important to provide a user focused approach to mine the maintenance data of buildings. The user focused approach for mining using four mining techniques (ID3, C4.5, Simple Kmeans and Association rules) has been developed and implemented for three asset types (Air Handling Unit, Battery Charger and Thermostat Mixing Valve) as a demonstration.

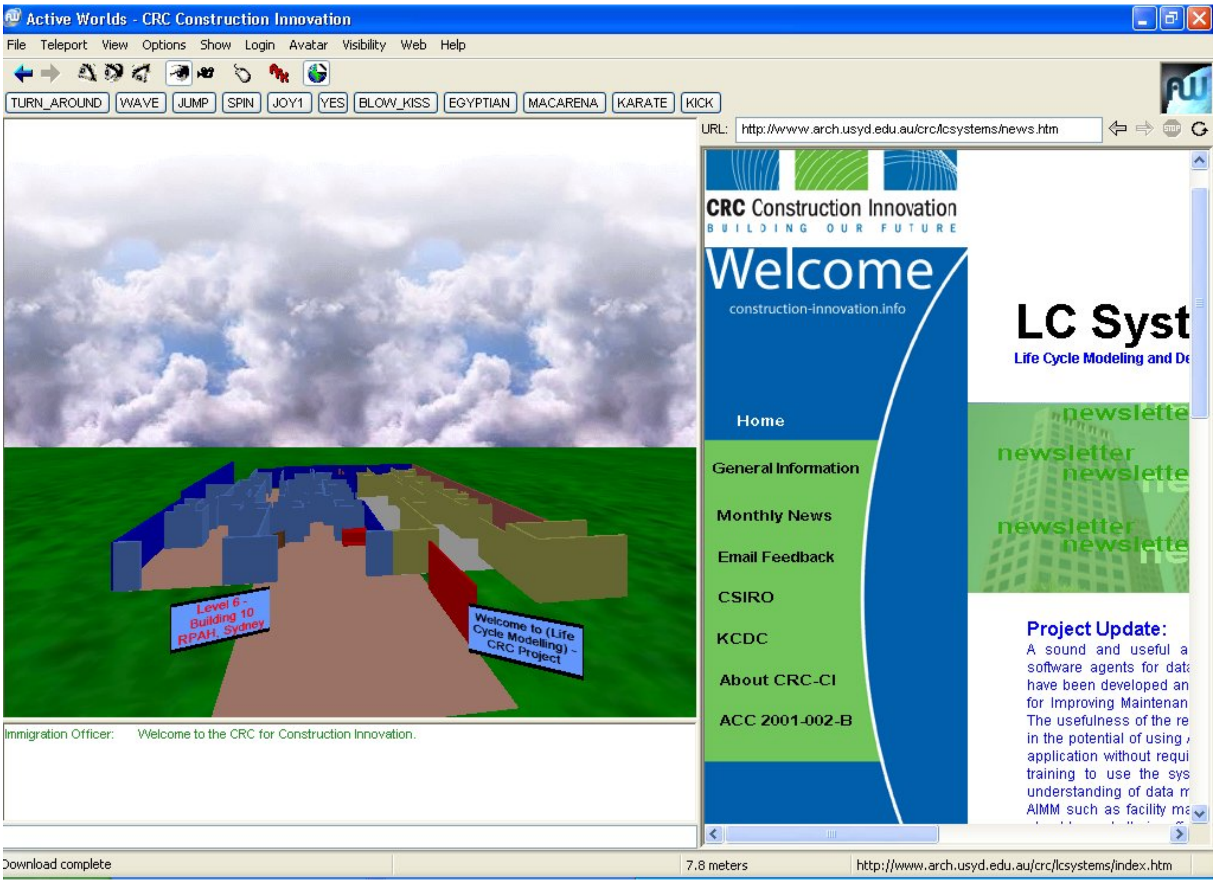


Figure 2.1 The primary interface of software agents prototype system [AIMM] in an interactive network multi-user environment.

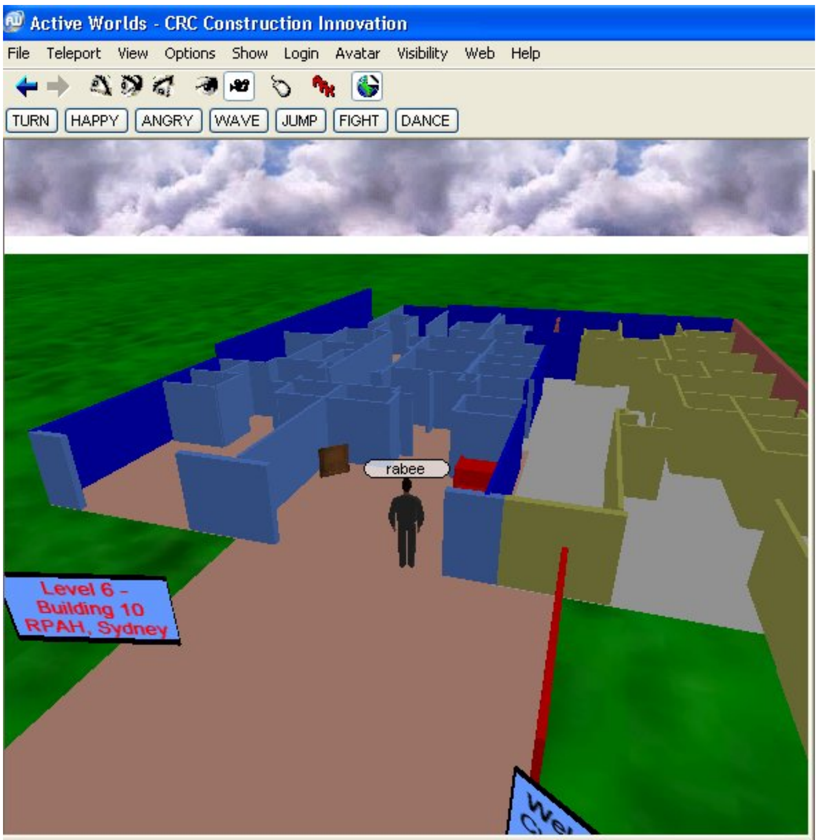


Figure 2.2 The user is represented by his selected Avatar in the interactive network multi-user environment.

## 2.1 A User Focused Approach on Mining Maintenance Data of the Air Handling Unit at Building no. 10 RPAH

The user may navigate within the 3D model of level 6, Building No.10 of RPAH at the network multi-user virtual environment. Once the user selects a building asset type such as the Air Handling Unit the object property window pops out describing general information of the selected object as shown in Figure 2.3. At the same time, the AIMM prototype system is instantiated as illustrated in Figure 2.4.

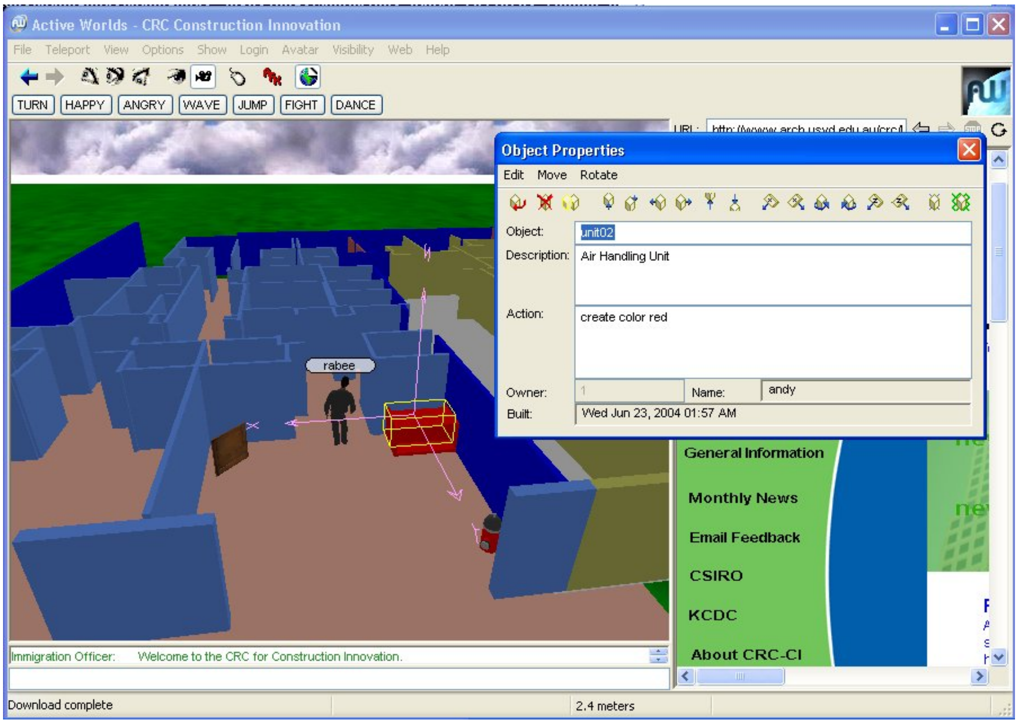


Figure 2.3 The user selects a building asset type (the Air Handling Unit) and an object property window pops out describing general information of the selected object.

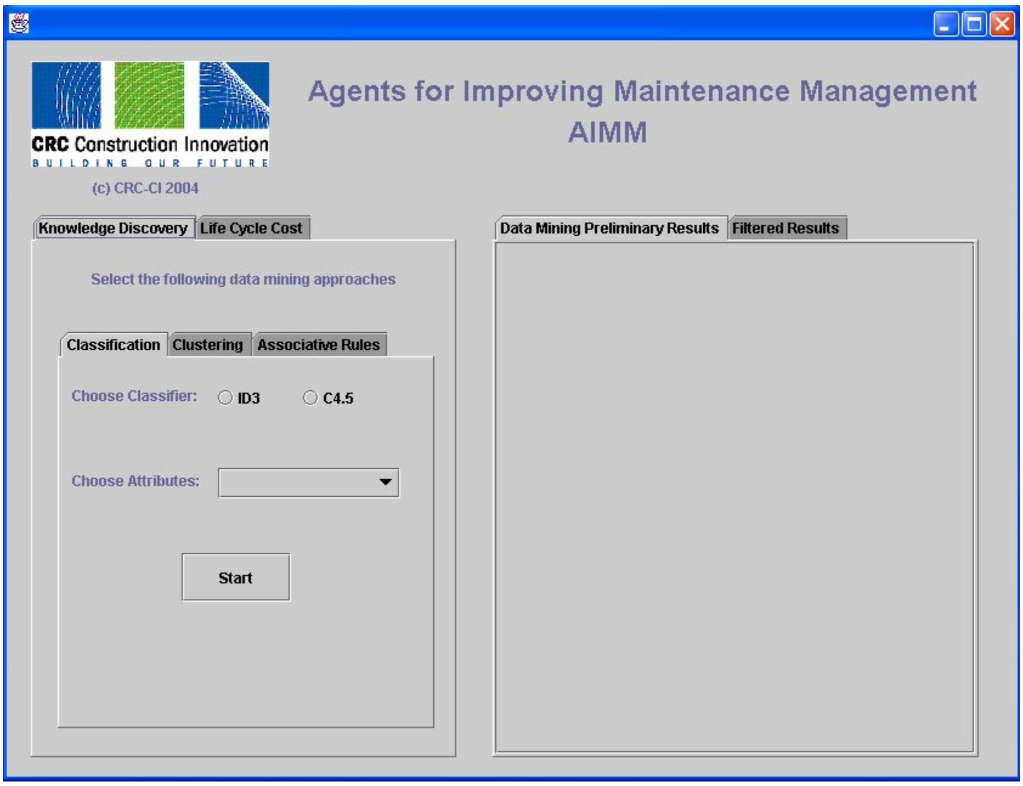


Figure 2.4 The AIMM prototype system is instantiated once a building asset type has been selected.

The user may choose any of the four data mining techniques (ID3, C4.5, Simple Kmeans and Association rules) and selects the attribute based on his/her focus and interest as shown in Figure 2.5. After a user selects a data mining technique, for instance ID3, a related ARFF data file will be parsed and attributes of the file will be feed into JComboBox, allowing a user to apply ID3 on various attributes to find rules and patterns of knowledge from the maintenance records of the Air Handling Unit as shown in Figure 2.6

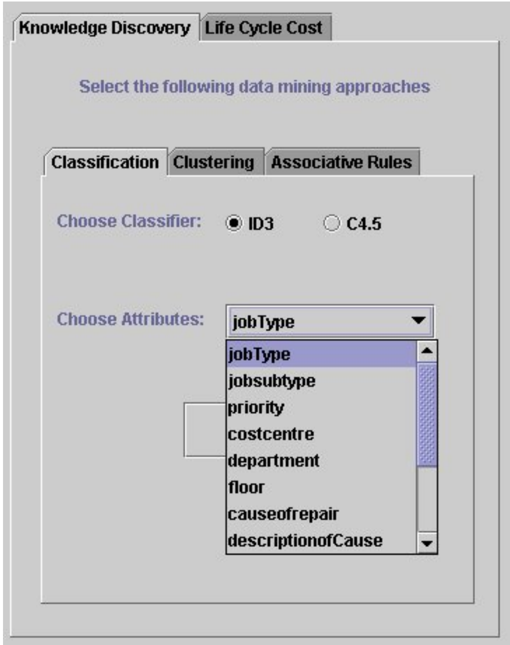


Figure 2.5 Data mining techniques and different attributes for the user to choose from based on focus and interest.

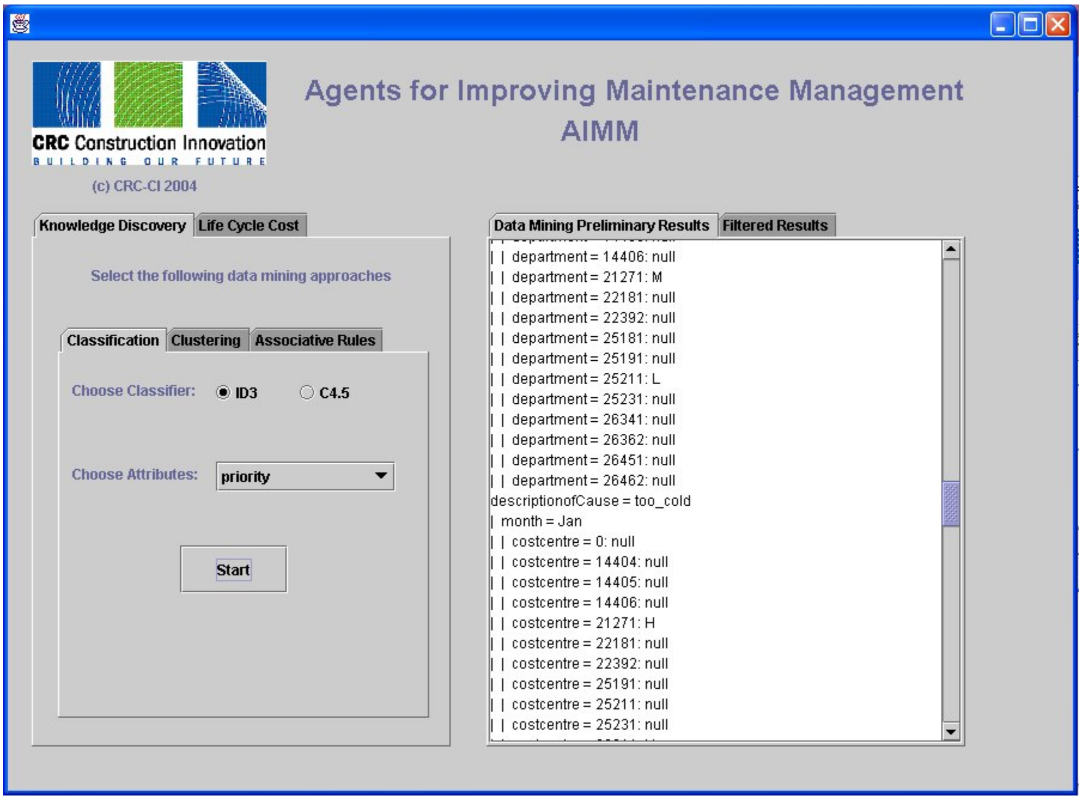


Figure 2.6 Preliminary results of applying the ID3 with the "Priority" attribute on the maintenance data of Air Handling Unit.

The user may select different attributes for classification and invokes the mining process using the Start button to obtain the preliminary results. Figures 2.7 and 2.8 show the results of mining using the ID3 on maintenance data of the Air Handling Unit with the attributes of “Work of Order Status” and “Cause of Repair” respectively.

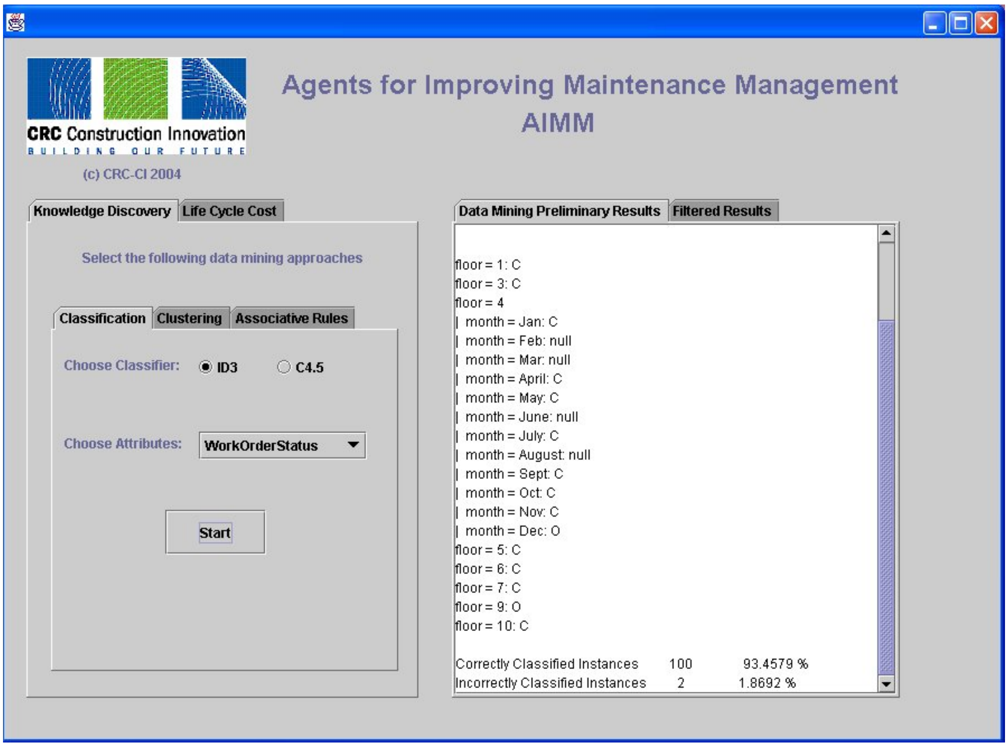


Figure 2.7 Preliminary results of applying the ID3 with the “Work Order Status” attribute on the maintenance data of Air Handling Unit.

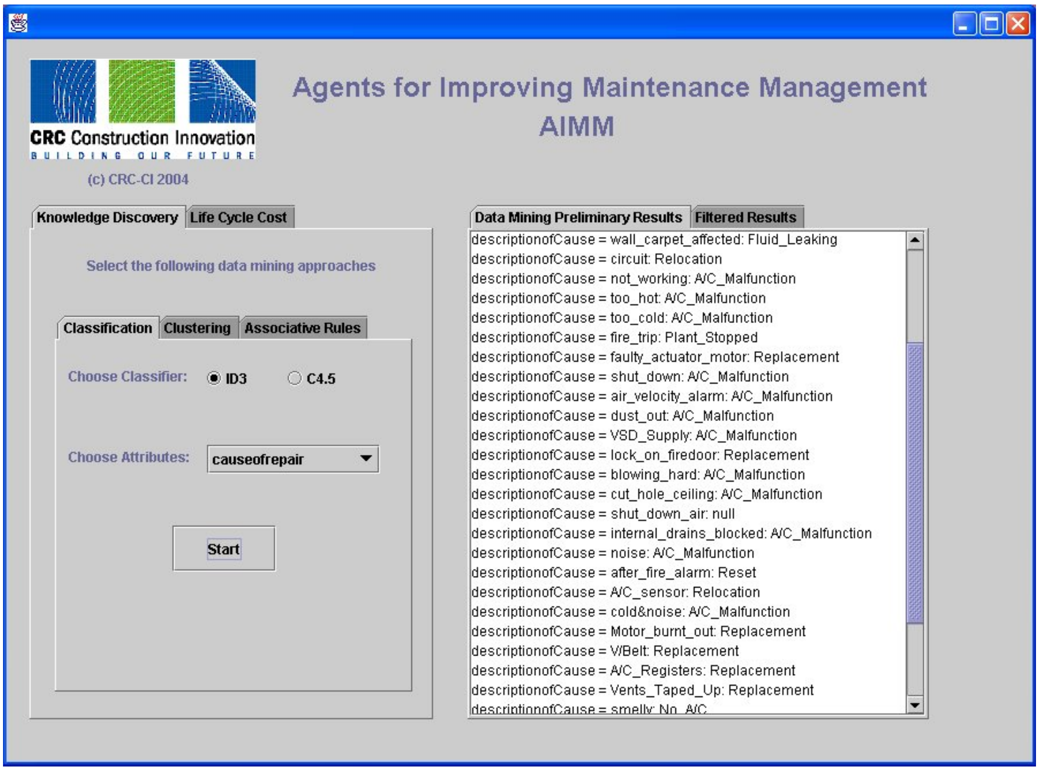


Figure 2.8 Preliminary results of applying the ID3 with the “Cause of Repair” attribute on the maintenance data of Air Handling Unit.

Similarly, the user may choose a different data mining technique with the same or different attributes for classification and invokes the mining process using the Start button to obtain the preliminary results. Figures 2.9 and 2.10 show the results of mining using the C4.5 on maintenance data of the Air Handling Unit with the attributes of "Description of Cause" and "Cost Centre" respectively.

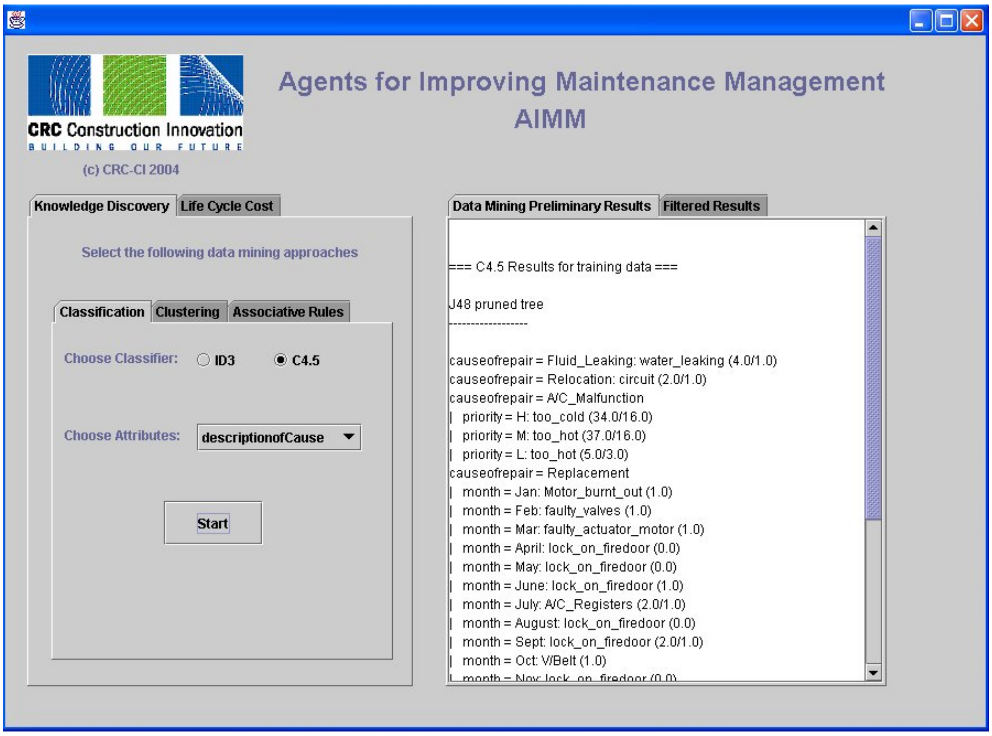


Figure 2.9 Preliminary results of applying the C4.5 with the "Description of Cause" attribute on the maintenance data of Air Handling Unit.

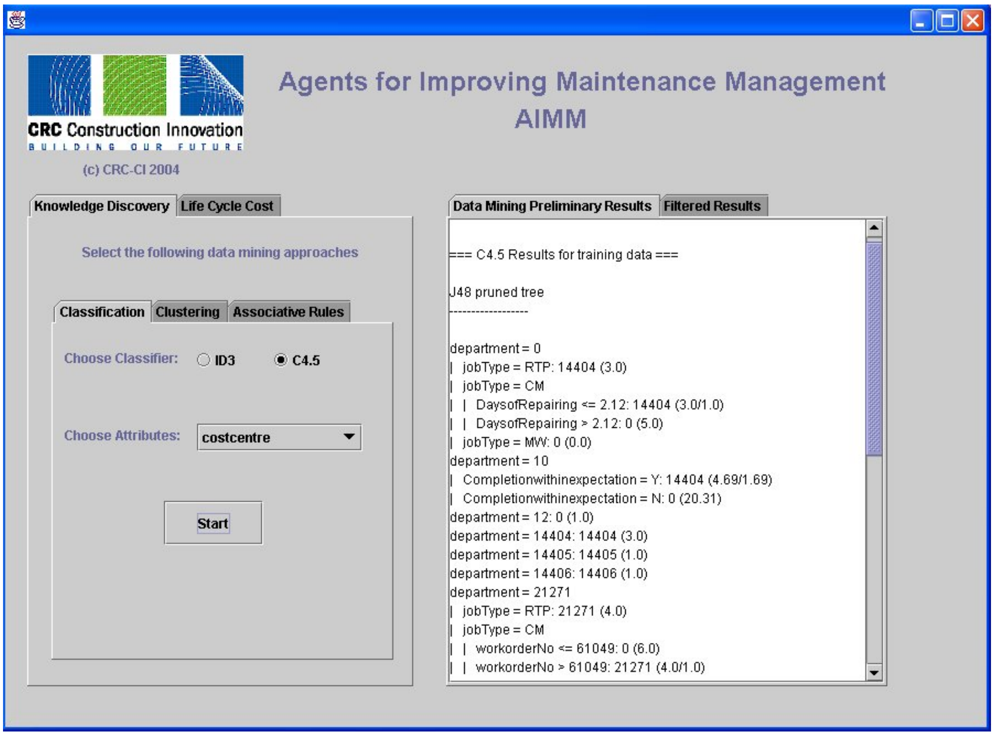


Figure 2.10 Preliminary results of applying the C4.5 with the "Cost Centre" attribute on the maintenance data of Air Handling Unit.

Furthermore, other data mining techniques such as the Simple Kmeans and Apriori with a selected associative group may be used to mine the maintenance data of Air Handling Unit as shown in Figures 2.11 and 2.12 respectively.

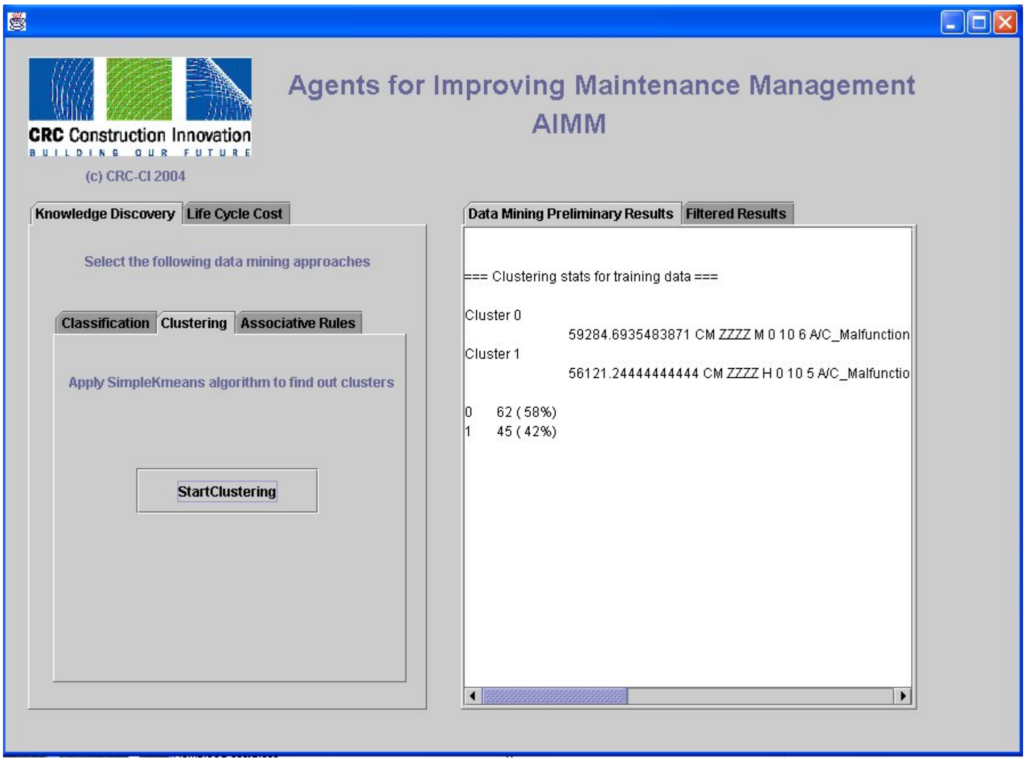


Figure 2.11 Preliminary results of applying the Simple Kmeans on the maintenance data of Air Handling Unit.

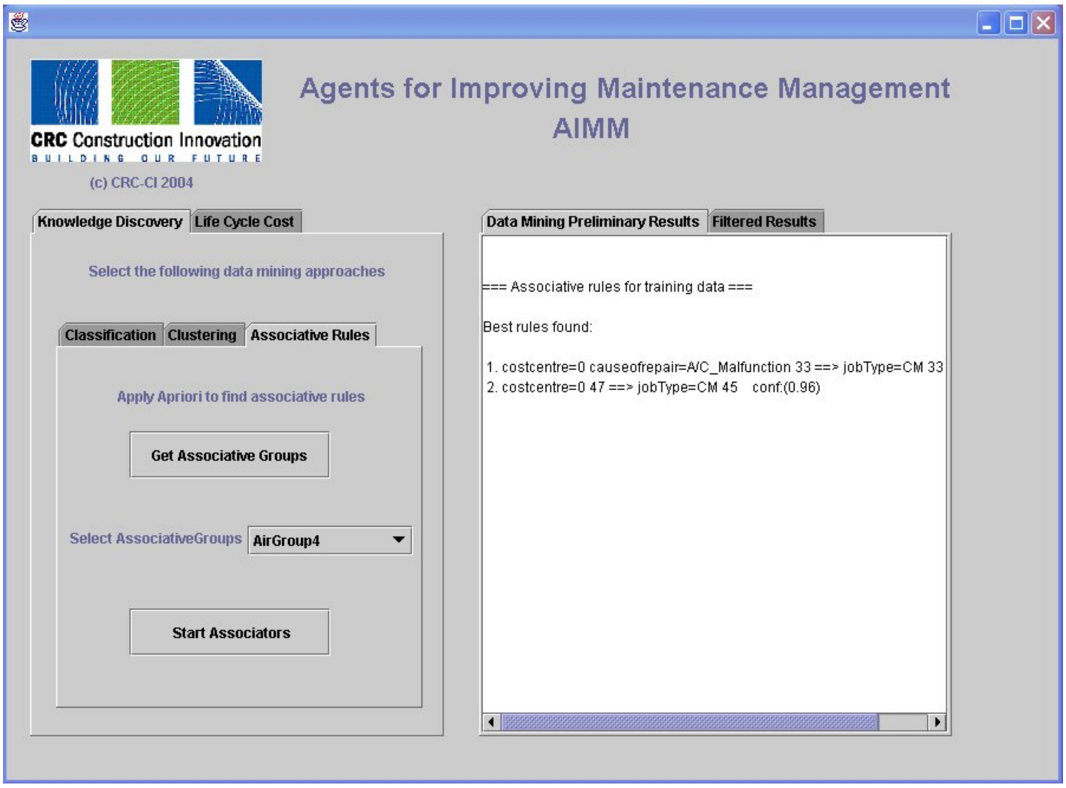


Figure 2.12 Preliminary results of applying the Apriori with associative group 4 on the maintenance data of Air Handling Unit.

## 2.2 A User Focused Approach on Mining Maintenance Data of the Thermostat Mixing Valve at Building no. 10 RPAH

Similarly, the user may select a different a building asset type such as the Thermostat Mixing Valve and the object property window will pop out describing general information of the selected object as shown in Figure 2.13. At the same time, the AIMM prototype system is instantiated and the user may select a data mining technique with an attribute of his/her choice for classification and invokes the mining process using the Start button to obtain the preliminary results. For instance, Figures 2.14, 2.15 and 2.16 illustrate the results of mining applying the ID3 on maintenance data of the Thermostat Mixing Valve with the "Priority" attribute, applying C4.5 with the "Frequency" attribute, and applying the Associative Rules respectively.

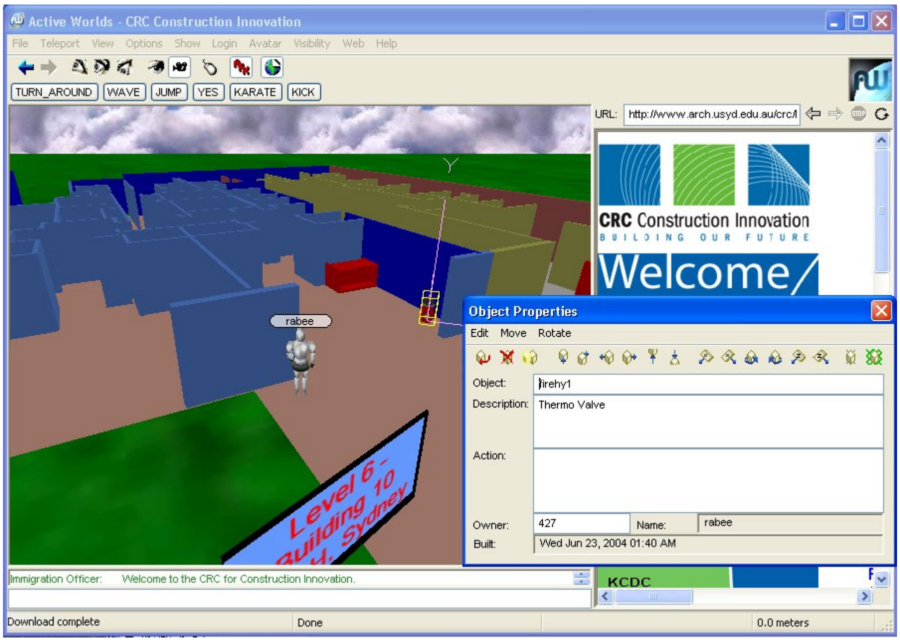


Figure 2.13 The user selects a building asset type (Thermostat Mixing Valve) and an object property window pops out describing general information of the selected object.

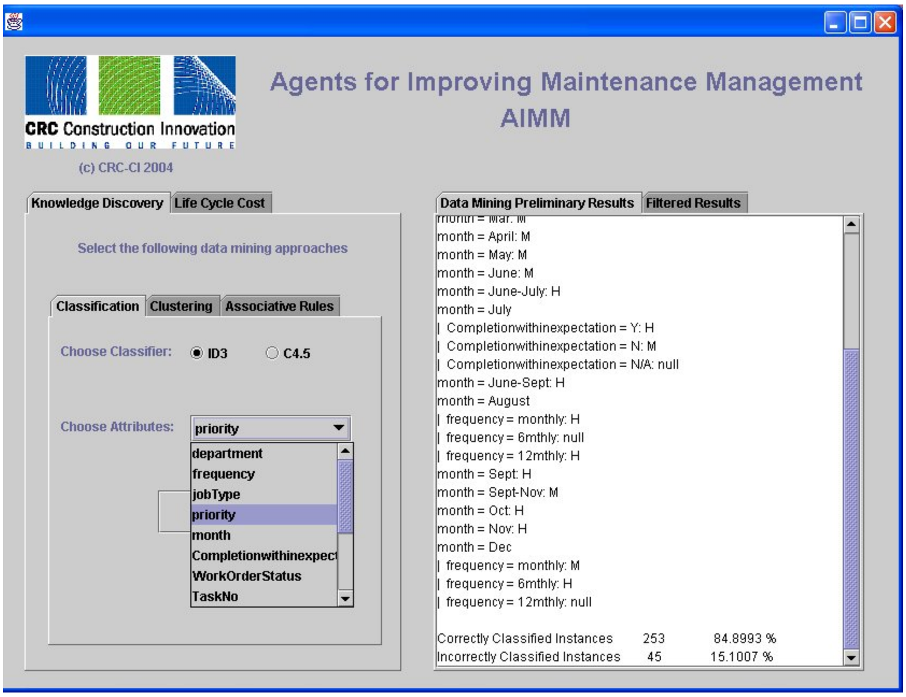


Figure 2.14 Preliminary results of applying the ID3 with the “Priority” attribute on the maintenance data of Thermostat Mixing Valve.

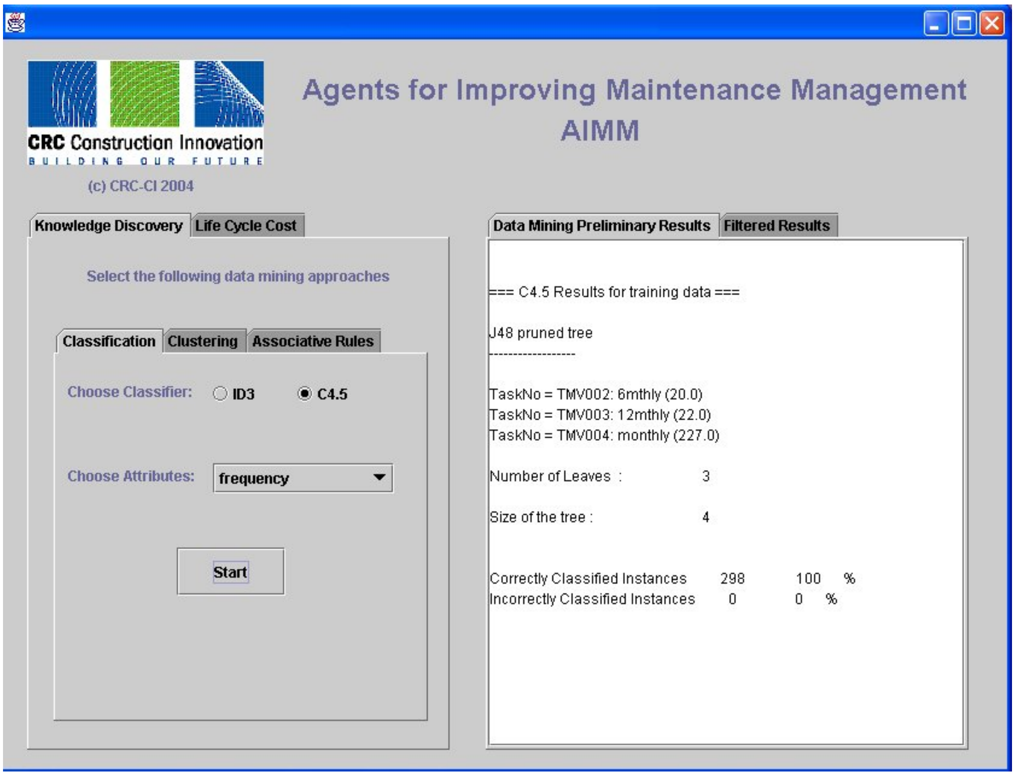


Figure 2.15 Preliminary results of applying the C4.5 with the “Frequency” attribute on the maintenance data of Thermostat Mixing Valve.

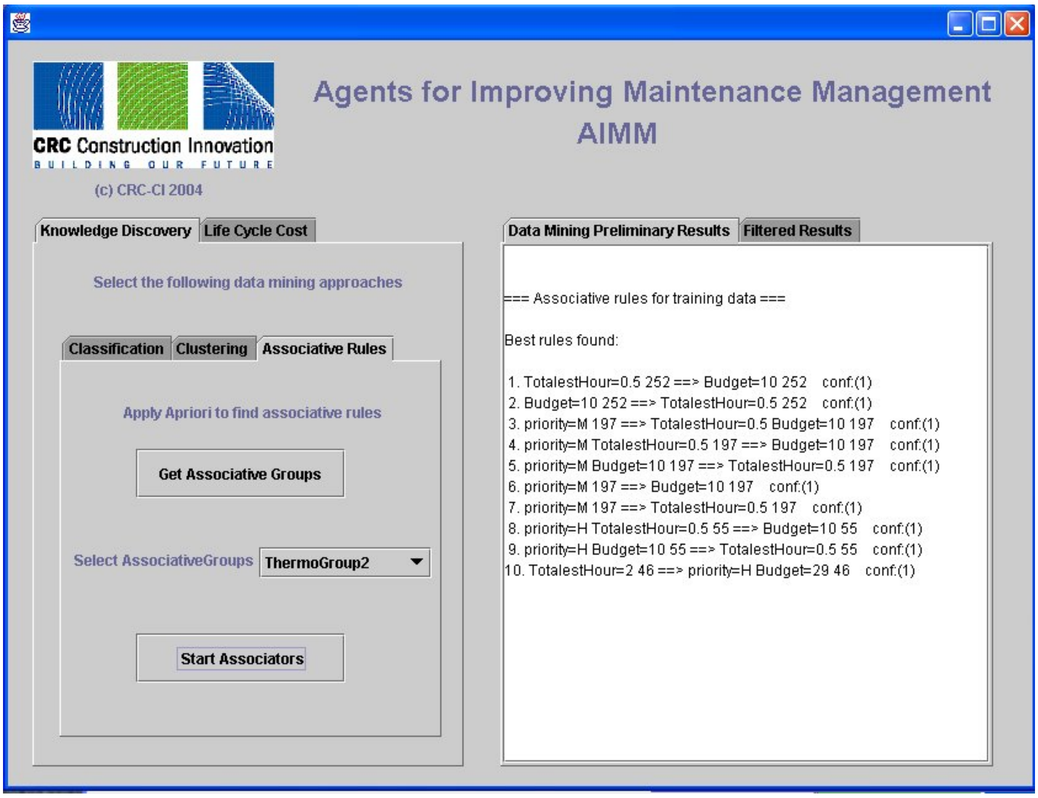


Figure 2.16 Preliminary results of applying the Apriori with associative group 4 on the maintenance data of Thermostat Mixing Valve.

## 2.3 A User Focused Approach on Mining Maintenance Data of the Battery Charger at Building no. 10 RPAH

Furthermore, the user may select a different building asset type such as the Battery Charger and the object property window will pop out describing general information of the selected object as shown in Figure 2.17. At the same time, the AIMM prototype system is instantiated and the user may select a data mining technique with an attribute of his/her choice for classification and invokes the mining process using the Start button to obtain the preliminary results. For instance, Figures 2.18 illustrates the result of mining using the ID3 on maintenance data of the Battery Charger with the “Month” attribute. Various data mining techniques with attributes of choice may be applied based on focus and interest.

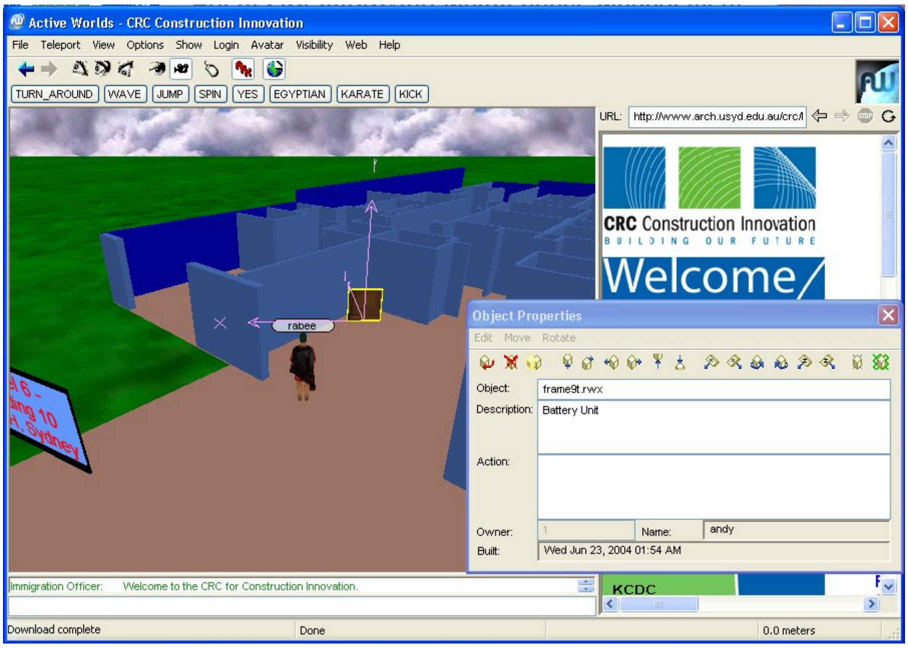


Figure 2.17 The user selects a building asset type (Battery Charger) and an object property window pops out describing general information of the selected object.

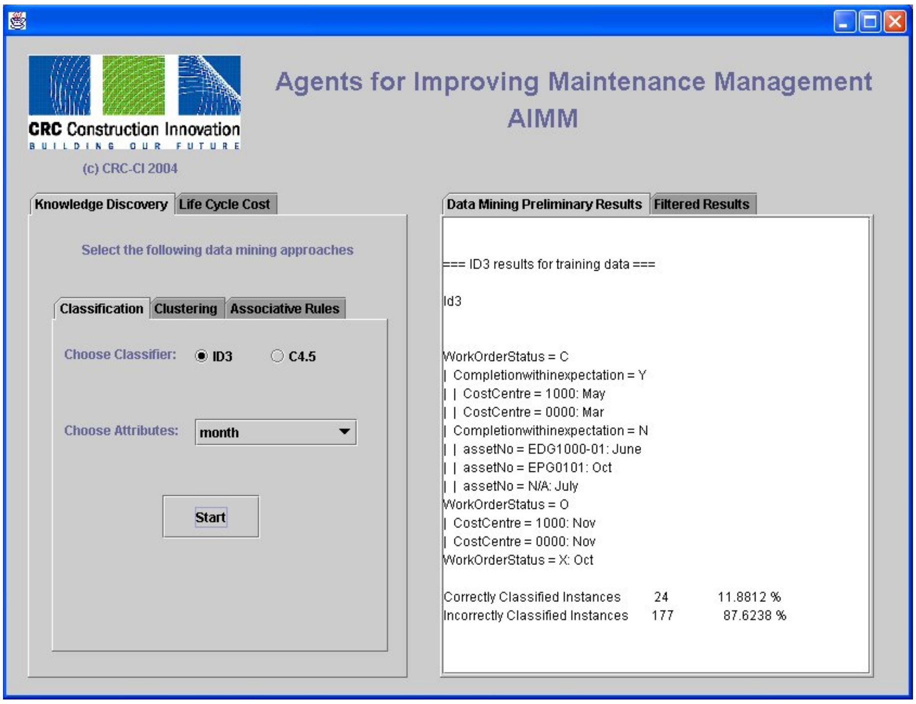


Figure 2.18 Preliminary results of applying the ID3 with the "Month" attribute on the maintenance data of Battery Charger.

# 2. DEVELOPING AND IMPLEMENTING A FILTERING AGENT ON THE RESULTS OBTAINED FROM APPLYING DATA MINING TECHNIQUES ON THE MAINTENANCE DATA

Filtering scenarios have been developed and implemented for three building assets including Air Handling Unit, Thermostat Mixing Valve and Battery Charger. These scenarios have been integrated within the structure of the Filtering Agent as shown in Figure 3.1 in order to improve the results of using AIMM to subsequently improve building life cycle, maintenance and operation. These filtering scenarios are illustrated in Tables 3.1, 3.2 and 3.3 for the asset types of Air Handling Unit, Thermostat Mixing Valve and Battery Charger respectively. Figure 3.2 illustrates examples the results of implementing the filtering scenarios with each of the four data mining techniques applied within the prototype system of AIMM. While Figure 3.3 illustrates an example of the filtered knowledge presented to the user from the preliminary results of applying the ID3 with the "Work Order Status" attribute on the maintenance data of Air Handling Unit.

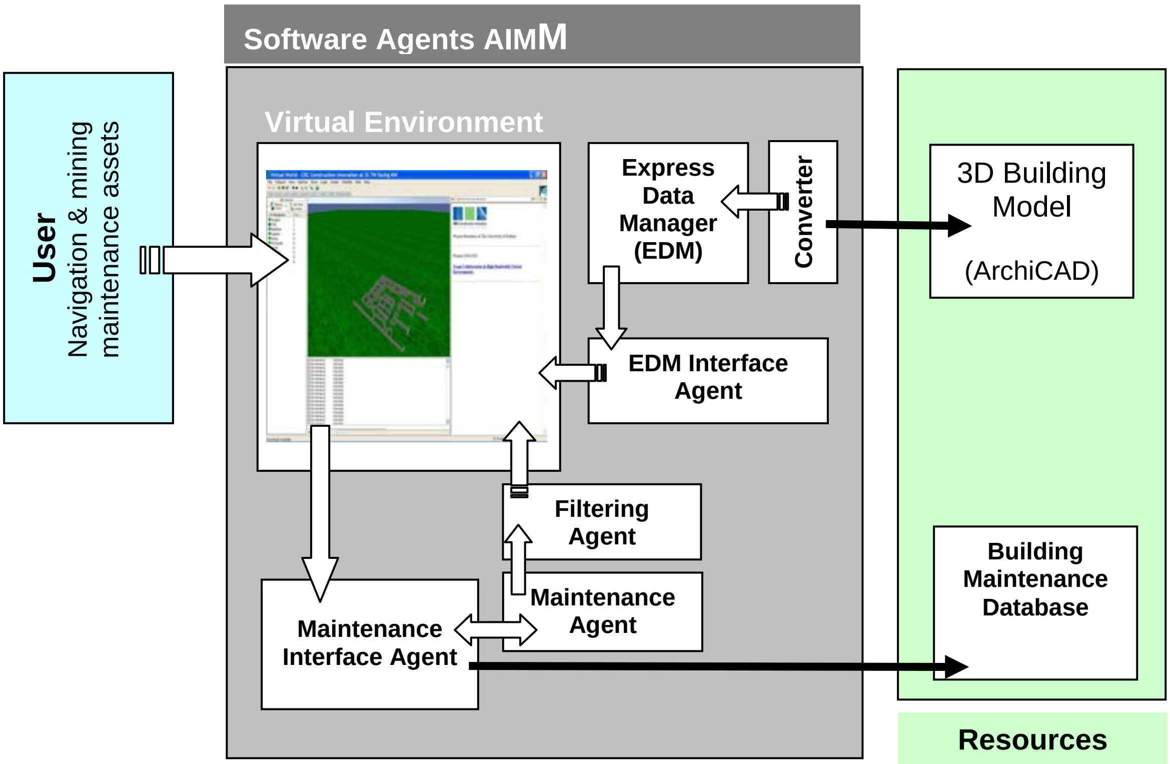


Figure 3.1 Developing and implementing the filtering scenarios within the structure of the Filtering Agent in AIMM.

Table 3.1 Filtering conditions and sets of knowledge presented to the user while mining the maintenance data of the Air Handling Unit.

<table>
<tr><th>Filtering Condition</th><th>Knowledge presented to the user</th></tr>
<tr><td>If the result contains a string pattern matching<br>"despcriptionofCause = too_cold ……. | floor = 7 || priority = H:N|| priority = M:N|| priority = L:Y"</td><td>Within the complaints related to air conditioning "too_cold", all the "high" and "medium" priority jobs were not completed within expectation. All the "low" priority jobs were completed on time; This may reflect a lack of supervision of high and medium priority air conditioning maintenance works in the facility management.</td></tr>
<tr><td>If the result contains a string matching<br>"floor=4 …… |month = Dec: O"</td><td>For floor 4, air handling unit maintenance works that occur in December are not likely to be completed – inspections are required to identify the causes of failure.</td></tr>
<tr><td>If the result contains a string matching<br>"department = 26462 | workorderNo<=50461:1(4.0) | workorderNo > 50461:7(11.0)"</td><td>Department 26462 resides only at $1^{st}$ and $7^{th}$ floor</td></tr>
<tr><td>If the result contains a string matching<br>"floor=7 25 = = > causeofrepair = A/C_Malfunction 25"</td><td>All air handling units maintenance works in floor 7 belong to A/C malfunction; failures are concentrated on a particular floor that requires further inspections.</td></tr>
<tr><td>If the result contains a string matching<br>"deparment = 26462 18 = = > causeofrepair = A/C_Malfunction 18"</td><td>All air handling units maintenance works in department 26462 belong to A/C malfunction; failure abnormally is concentrated on a particular department, which requires further inspections.</td></tr>
<tr><td>If the result contains a string matching<br>"deparment = 21271 16 = = > floor = 6 16"</td><td>Department 21271 resides only at $6^{th}$ floor.</td></tr>
<tr><td>If the result contains a string matching<br>"floor=7 25 = = > completionwithinexpectation=N 23"</td><td>Maintenance works at Floor 7 are most likely not meeting expectations: with 23 out 25 completionwithinexpectation = "N" (92%), further inspection is required by facility manages to identify reasons of failure.</td></tr>
<tr><td>If the result contains a string matching<br>"costcentre=0 47 = = > jobType=CM 45"</td><td>96% of maintenance jobs of Cost Centre are corrective maintenance.</td></tr>
<tr><td>If the result contains a string matching<br>"Cluster0 ….. A/C_Malfunction too_hot …… Cluster 1 …… A/C_Malfunction too_cold"</td><td>Illustration of centroid as "too_hot" and "too_cold" and their corresponding percentages are "62%" and "45%" respectively.</td></tr>
</table>

Table 3.2 Filtering conditions and sets of knowledge presented to the user while mining the maintenance data of the Thermostatic Valve.

| Filtering Condition | Knowledge presented to the user |
|---|---|
| If the result contains a string matching<br>"frequency = monthly \| priority = H \|\| Completionwithinexpectation = Y:July\|\| Completionwithinexpectation = N:August" | For all monthly high priority maintenance works, all the works in July were completed within expectation and those in August fail. Possible reasons of failure might be due to seasons' resulting weather and humidity. |
| If the result contains a string matching<br>"frequency = monthly …… \| priority = M \|\| Completionwithinexpectation = Y:Jan\|\| Completionwithinexpectation = N:June" | For all monthly medium priority maintenance works, all the works in January were completed within expectation and those in June fail. Possible reasons of failure might be due to specific months of operation or the resulting weather and humidity. |
| If the result contains a string matching<br>"month=Jan:Y month=Feb:N month=Mar:N month=April:N month=May:Y month=June:N ……" | Maintenance works in January and May were completed within expectation. This is possibly related to season, temperature or differences of humidity. Other reasons might include maintenance teams or personnel. |
| If the result contains a string matching<br>":L4" | All Thermostat Mixing Valves maintenance works took place at Floor No. 4. |
| If the result contains a string matching<br>"StartDate > 1023926400000: H (61.0)" | Starting Date after the date that its value equals to "1023926400000" must belong to high priority work. An emergent trend of extensive maintenance of thermostatic valves should be investigated. |
| If the result contains a string matching<br>"CompletionDate > 989741520000: N" | Most thermostatic valve maintenance works (211 out of 213) completed after the date "989741520000" did not meet expectations. Further investigations are required |
| If the result contains a string matching<br>"workorderNo <= 72085: C (255.0)" | Jobs with WorkorderNo <=725085 were all completed. |
| If the result contains a string matching<br>"Completionwithinexpectation=Y 49 = = > priority=M 47" | 96% of thermostatic valve maintenance works with completions meeting expectation are of medium priority. |
| If the result contains a string matching<br>"frequency=monthly 252 ==> WorkOrderStatus=C 252 conf:(1)" | All monthly maintenance works were completed. |
| If the result contains a string matching<br>"Cluster0 ….. monthly SM M …… Jan …… Cluster 1 …… monthly SM H …… Dec" | Illustration of centroid as "Medium Priority Job in January" and "High Priority Job in December" and their corresponding percentages are "66%" and "34%" respectively. |

Table 3.3 Filtering conditions and sets of knowledge presented to the user while mining the maintenance data of the Battery Charger.

| Filtering Condition | Knowledge presented to the user |
|---|---|
| If the result contains a string matching<br>“workorderNo > 66195: N (30.0)” | All recently issued maintenance jobs were not completed within expectation. |
| If the result contains a string matching<br>“workorderNo <= 70266: C (168.0/1.0)<br>workorderNo > 70266: O (14.0/4.0)” | Most of previously issued maintenance works have been completed, while most of (12 out of 14) recently issued works were not completed. |
| If the result contains a string matching<br>“Cluster0 ….. M May…… EPG0101 …… Cluster 1 …… M April …… EDG1000-01” | Illustration of centroid as “Medium Priority Job in May on EPG0101” and “Medium Priority Job in April on EDG1000-01” and their corresponding percentages are “50%” and “50%” respectively. |

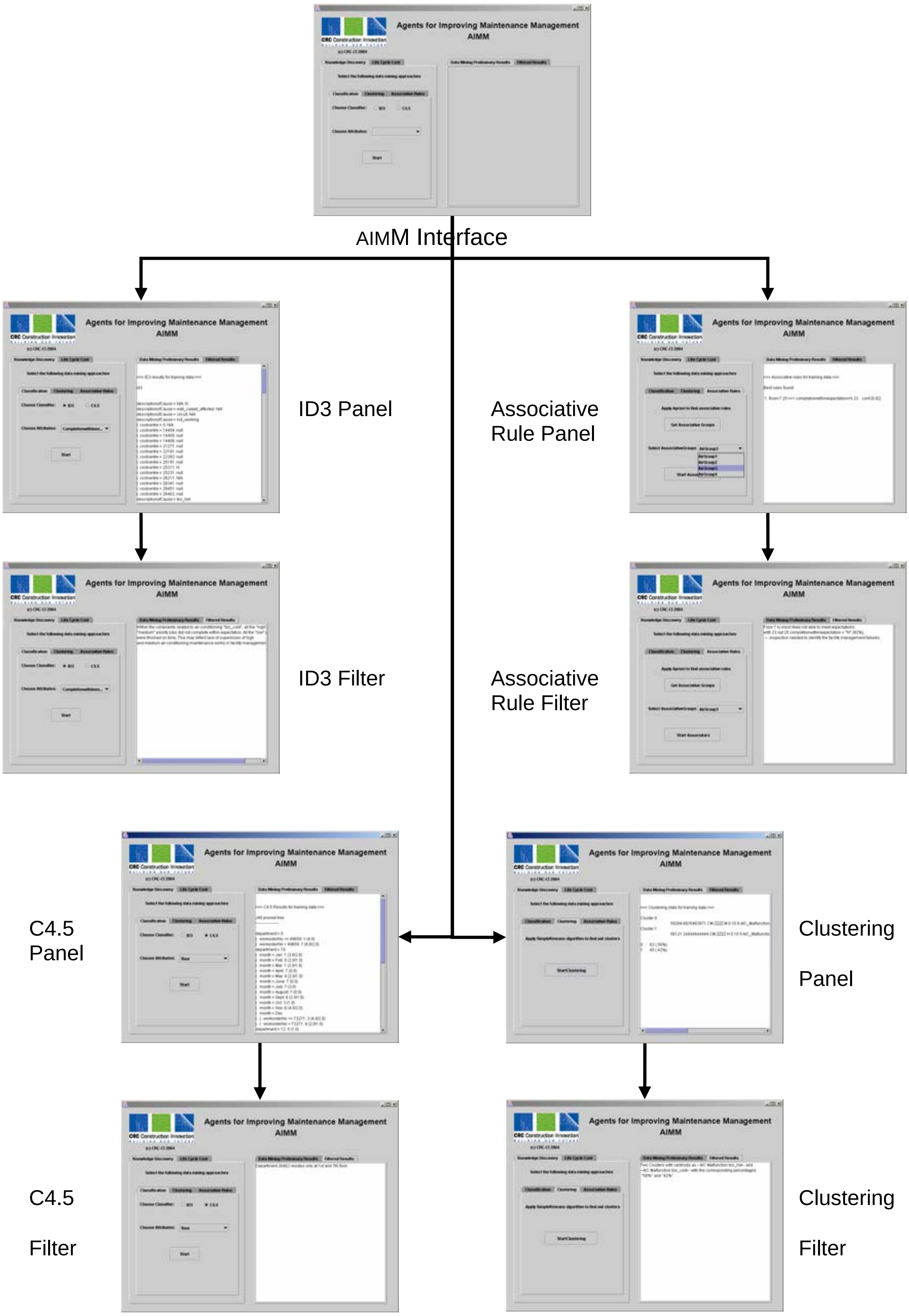


Figure 3.2 Examples the results of implementing the filtering scenarios with each of the four data mining techniques applied within the prototype system of AIMM.

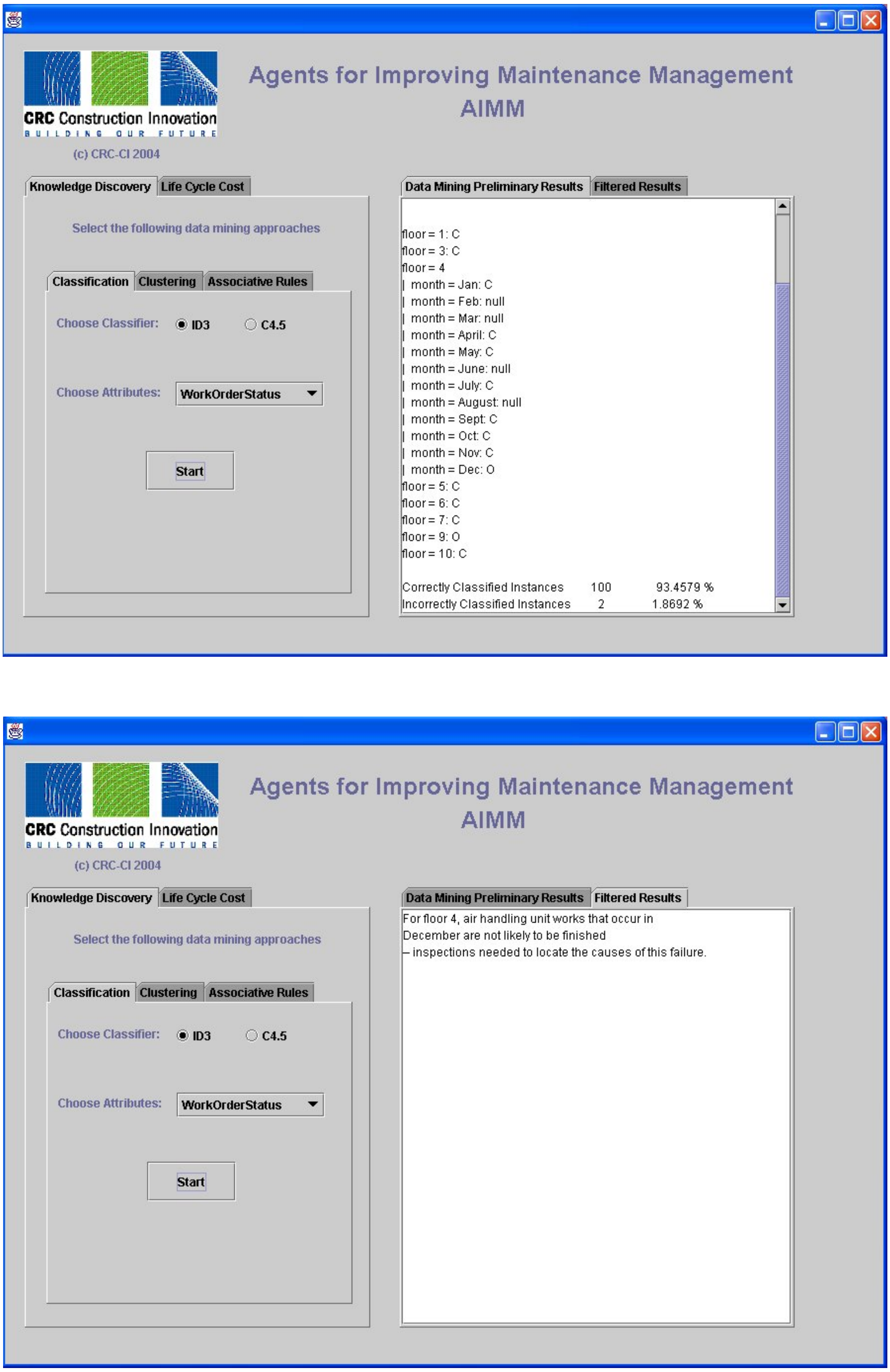


Figure 3.3 An example of the filtered knowledge presented to the user from the preliminary results of applying the ID3 with the "Work Order Status" attribute on the maintenance data of Air Handling Unit.

# 3. POPULATING MAINTENANCE DATA

The results obtained from applying data mining techniques on maintenance data are not static; they change as the data changes. Some patterns of knowledge might be reinforced and others might be decayed. Furthermore, new forms or patterns of knowledge might be discovered. This is a phenomenon that makes the result obtained from the prototype system of AIMM be dynamic and reflect the changes in the source data. For instance, Table 4.1 illustrates the results of applying the Simple Kmeans on the maintenance records of the Air Handling Unit at a certain point of time. At a later time after further maintenance jobs have been requested and completed a new behaviour of the Cause of Repair has been discovered as shown in Table 4.2 after applying the Clustering on the populated maintenance data.

Table 4.1 An example of clustering results from the maintenance data of the Air Handling Unit at an earlier time of maintenance records.

| Clustering results from the maintenance data of Air Handling Unit at an earlier time of maintenance records |
|---|
| === Clustering stats for training data === |
| Cluster 0 |
| 59284.6935483871 CM ZZZZ M 0 10 6 A/C_Malfunction too_hot Adjust Mar WOS 4.466612903225806 4.464838709677419 9.444663594470049 N 0.0 0.0 0.0 C |
| Cluster 1 |
| 56121.24444444444 CM ZZZZ H 0 10 5 A/C_Malfunction too_cold Adjust Jan WOS 10.108878406708598 9.391638095238095 11.785536507936508 N 0.0 0.0 0.0 C |
| Clustered Instances |
| 0 62 ( 58%) |
| 1 45 ( 42%) |
| Two Clusters with centroids as --A/C Malfunction too_hot-- and |
| --A/C Malfunction too_cold-- with the corresponding percentages "58%" and "42%" |

Table 4.2 An example of new clustering results from the maintenance data of the Air Handling Unit at a later time of maintenance records.

| Clustering results of the populated maintenance data of Air Handling Unit |
|---|
| === Clustering stats for training data === |
| Cluster 0 |
| 58684.905263157896 CM ZZZZ M 0 10 6 A/C_Malfunction too_hot Adjust Mar WOS 5.7881052631578935 5.791894736842104 10.057578947368421 N 0.0 0.0 0.0 C |
| Cluster 1 |
| 64047.48 CM ZZZZ H 0 10 4 Fluid_Leaking water_leaking Adjust Jan WOS 9.592426890756308 8.201105084745768 11.841085714285715 N 0.0 0.0 0.0 O |
| Clustered Instances |
| 0 95 ( 79%) |
| 1 25 ( 21%) |
| A new cluster is discovered by applying the Simple Kmeans on maintenance data including newly added maintenance records |

Furthermore, by applying the C4.5 data mining technique with the “Work Order Status” attribute on the maintenance data including newly added records a new rule has been discovered as shown in Table 4.3; that is maintenance jobs with Work Order No. greater than 73675 represent all outstanding maintenance work. Also by applying C4.5 on the populated maintenance data with the “Month” attribute, a new rule was discovered; Most of the “Fluid leaking” occur in January and are billed in costcentre 0 (14 out of 16).

Table 4.3 An example of new rule discovered by applying the C4.5 with the “Work Order Status” attribute on the populated maintenance data of the Air Handling Unit

| Applying C4.5 on attribute “WorkOrderStatus” |
| --- |
| === C4.5 Results for training data === |
| J48 pruned tree |
| ------------------ |
| workorderNo <= 73675: C (96.0/1.0) |
| workorderNo > 73675: O (12.0) |
| Number of Leaves : 2 |
| Size of the tree : 3 |
| Correctly Classified Instances 118 98.3333 % |
| Incorrectly Classified Instances 2 1.6667 % |

# 4. CONCLUSION

A software agents prototype system has been developed, implemented and integrated in an interactive networked 3D virtual environment that promotes multiple participant involvement within which life-cycle modelling agents function and maintenance data are linked to the 3D product model of the physical building.

The prototype system can be accessed from anywhere without a concern for geographic location by different users simultaneously while users will be aware of the presence of others within the same environment. Users such as facility managers may choose to conduct a meeting, leaving a note to others about a specific building asset type next to the 3D object representing this asset in the 3D virtual environment. Each user may use the prototype system to mine the maintenance data based on their focus and interest. Users might be looking at different building assets and using different mining and discovery techniques than others within the same environment while talking to each others synchronously. Each user may be represented by a selected Avatar to navigate, walk through and fly within the 3D virtual environment. Users can have access to the software agents prototype system in an interactive networked multi-user 3D virtual environment by installing the client software of the network multi-user virtual environments (Active Worlds) at their own computers and access the server remotely whereas the prototype system should be available at their computers.

In order to improve the results obtained from applying AIMM on maintenance data, appropriate data mining scenarios and filters have been developed and implemented. However, the results of the filtering agent should be more user friendly. The filtering agent and its associated filtered knowledge will be further refined to be more user friendly during the coming quarter.

The application of AIMM system prototype on the available maintenance data has been utilised on three asset types (air handling units, thermostat mixing valve and battery charger). The AIMM system prototype has been applied on the populated maintenance data whereby new rules were discovered.

The other deliverables of this Quarter includes developing a proposal for a project extension. This proposal will be submitted, presented and discussed with the Industry Partners during July 2004 in Brisbane. A preliminary demo of life cycle cost agent that has been developed and implemented will be demonstrated during the presentation with Industry Partners. Furthermore, the complete draft of research paper on agents-based approach to maintenance data mining will be forwarded to the CRC during the mid of coming Quarter prior to sending it for journal publication.

The deliverables in the coming quarter (due on 30 September 2004) include: (a) Demonstration System, (b) Completion of draft of research paper on agents-based approach to maintenance data mining, (c) Industry focused report for dissemination, (d) Flyer for CRC promotional purposes and (e) Delivering workshops demonstrating prototype system with data mining of maintenance data.