Expert Provisioner:
A Range Management Aid

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Abstract

Expert Provisioner is a knowledge-based provisioning system prototyped for use by the RAF Logistics Command to support their Range Managers in the procurement of consumable parts. It was jointly developed by AIAI at the University of Edinburgh and Logistics Research (LR) branch of the RAF.

Spares re-provisioning is one of the most fundamental and difficult logistics processes. Any item of equipment will need to have some of its component parts replaced at some time during its operational life. Re-provisioning is the art of ensuring that spare parts are available when required without tying up much needed capital in excessive inventory holdings. To conduct re-provisioning properly requires a great deal of specific knowledge about item characteristics and customer requirements, coupled with a high level of expertise in re-provisioning procedures. The RAF has lost many of its most experienced Range Managers in the last few years. To address this situation the knowledge based system (KBS) entitled "Expert Provisioner" is being developed.

The starting point for Expert Provisioner is an electronic purchase order form and its end point is a recommendation of whether to buy the item or not, its cost and due delivery date. Purchase recommendations are made based on many factors including forecast demand, unit costs, shelf life and existing stock levels. The system removes much of the mundane work in order processing as well as potential for misinterpretation of information. The system is designed such that the user remains in control throughout the consultation and can, if desired, override decisions. Expert Provisioner was implemented using the NASA CLIPS development tool for the inference engine and knowledge base. The system was developed and delivered under Windows 3.1 through the use of AIAI's multi-platform wxCLIPS tool for the user interface.

The benefits identified and proved through the development of the Expert Provisioner prototype are: improved speed and accuracy of the data checking and order quantity calculation processes; automatic recording of provisioning history data for use in Financial Management/Analysis; and finally the ability to allow trainees to work on real life problems and compare their results with the experts. Having proved the benefits to be gained by a KBS, the next stage is to move to the Expert Provisioner production model. This will initially be developed to handle consumables for a single aircraft, but eventually, it will be rolled out for all aircraft and its functionality will be expanded to include repairable items as well as consumables.

1. Problem Description

The Royal Air Force manages over a million inventory items of which over 80% are consumable stores (items of material, normally of low monetary value, that are consumed or used to destruction in service, or which are regarded as expended on issue, e.g. paint, a vehicle spare, etc). These consumable items are divided into a number of "ranges" (subcategories) which contain items of a similar nature or which make up the same end item (an aircraft). The various ranges are sub-divided into more specialist areas and a Range Manager is charged with the upkeep of that particular range of items. The reorder cycle for these items is triggered by the stock level of an item falling below a calculated level. This generates a "Request for Provision" form for that item which is sent to the Range Manager. This form contains much information on that item, including past provisioning history, price and so on, and recommends an order quantity. The Range Manager must decide if the recommended order should be accepted by scrutinising the data, and by using other documentation, laid down rules and experience. A good Range Manager looks for combinations of data which pass unnoticed by the computerised re-ordering system, for alternative sources of spares within the RAF Logistics system, and for order quantities which are unreasonably high due to obsolescence or shelf life. On the basis of these factors, an experienced Range Manager will "nil buy" (i.e. reject as unnecessary) a large percentage of all Requests for Provision.

It has long been recognised within the RAF that the management of their inventory of over 1 million line items is a very complicated task. In the present climate of draw down, cut back and value for money, the more efficiently this inventory can be managed the better. Currently, the RAF is attempting to rationalise its inventory holdings - disposing of surplus stocks of items and trying to ensure that orders for new quantities of goods are both cost effective and pertinent to the need. However, just as the new climate requires more efficiency and accountability, the changes engendered by this new climate mean that the core of the RAF's expertise in this area has been lost. A relocation of the main supply centre resulted in many of the most experienced Range Managers leaving via redundancy or to work in other areas, creating a skills gap in the very area expertise is required. Many Range Managers stay in the job for 2-3 years and then have to seek promotion in other areas because of limited opportunities for advancement as a Range Manager. The combined result of this has been a steady loss of expertise over the years, which in turn means that a task crucial to the RAF's short term (and, more importantly, long term) future is being performed by personnel who might not have as much experience and business knowledge as they should.

Any solution to this problem had to address two areas:

1. How to aid Range Managers to make better, more informed decisions.
2. How to capture and preserve the knowledge and expertise of Range Managers and pass it on to new generations of trainees.

A knowledge based system (KBS) is ideally suited to this type of problem. Each range of items has a different set of rules that define the way it is handled and the flexibility that a KBS provides allows all these variations to be incorporated in the application. It is also possible to update the rule base as the rules change to accommodate changing parameters or changes in the business environment. Specifically, a KBS was used in the solution of this particular problem for the following reasons:

a. It provides a permanent, flexible, source of on-line expert knowledge. Thus, unlike human experts, the KBS is always available for consultation and the KBS rule base can be adapted as needed to accommodate the dynamics of changing procedures.

b. Suggestions and recommendations produced by a KBS result from the consistent, unemotional application of the expert knowledge base.

c. In addition to aiding the decision process, it provides an extensive training utility via the use of on-screen help and explanation facilities. Thus, through use of a KBS, inexperienced workers can carry out the job and make informed decisions while they gain job expertise.

Expert Provisioner (EP) was jointly developed by the Artificial Intelligence Applications Institute (AIAI) at the University of Edinburgh and the Logistics Research (LR) branch of the RAF to provide such a solution. The rule base is written as a separate module and interfaces to other modules that contain, for example, a data checking module or an order quantity calculation module. This modular construction introduces yet more flexibility and allows other modules to be interfaced as they are developed, allowing Expert Provisioner to expand to meet future requirements.

2. Application Description

The Role of the Expert Provisioner

The Supply Central Computing System (SCCS) keeps track of the entire RAF inventory and each month reviews the stock level of every consumable item to determine which have fallen below the re-ordering threshold. When this happens, a “Request for Provision” (R001) form is produced by the SCCS; batches of these forms are distributed monthly to Range Managers. The Range Manager has to decide whether to accept the suggested order quantity or whether to input an order of his or her choice.

The Range Manager must check the R001 data for consistency with known parameters, consult Annual Price Lists, reference manuals, lookup tables and the item’s Master Provisioning Record Card (MPRC), which contains a full purchase history, and other important details which are not recorded by SCCS. If changes are needed to individual data, the Range Manager must recalculate the order quantity manually, update any changed parameters which are recorded on the central system (if they have been changed from the original values), decide on the requisite quantity to order and record this order together with the contract number and the value of the order on the item's MPRC.

Expert Provisioner was designed to aid in four main areas:

1. Gathering information. Expert Provisioner includes an electronic version of the Master Provisioning Record Card (MPRC), which is automatically generated for each item if it does not already exist. Data from the many sources that the Range Manager has to consult are collated into the on-line MPRC, allowing easy access to all relevant data.

2. Data checking and order calculation. The R001 data (in electronic format) is checked by passing the data through a rule base which encapsulates the expert knowledge of many experienced Range Managers. These rules check for discrepancies in the data and flag up problems, giving suggestions on how to deal with them (including recommending "nil buys") and guidelines on how they will affect the order process.

   Once the data has been 'cleansed' in this way it is passed through to an application called Miniprov which uses the same algorithms as the SCCS to calculate suggested order quantities. Miniprov produces two order quantities**:** one mirrors the SCCS order and the second reflects any changed parameter values that are the result of the data passing through the rule base. Miniprov allows the Range Manager to perform 'what if' enquiries with the various parameter values and also provides the facility for the Range Manager to input an arbitrary order quantity should they so wish. Expert Provisioner then automatically selects an "Amended Buy Code" which explains the reasons for the amendment, and appends it to the order details

3. Recording decisions made. Once an order quantity has been decided, Expert Provisioner has the capability to record the order along with the contract number and the value on the electronic MPRC. This purchase history builds up over time and provides the base data for the RM and/or senior staff to query for details of financial obligations, commitments and budgetary matters. Expert Provisioner will also produce the required order documents for transmission to the contractors concerned.

4. Training aid. Through the use of help menus and 'Explanation Buttons' (at any stage an explanation of a rule or process can be accessed), Expert Provisioner provides a comprehensive training aid for trainee Range Managers. In addition, a log of every decision made during the 'consultation' with Expert Provisioner is kept and can be used to compare trainees' efforts with experienced Range Managers who have dealt with the same R001 in the past.

Figure 1 shows the basic elements of Expert Provisioner - these elements are present in both the prototype and the production models.

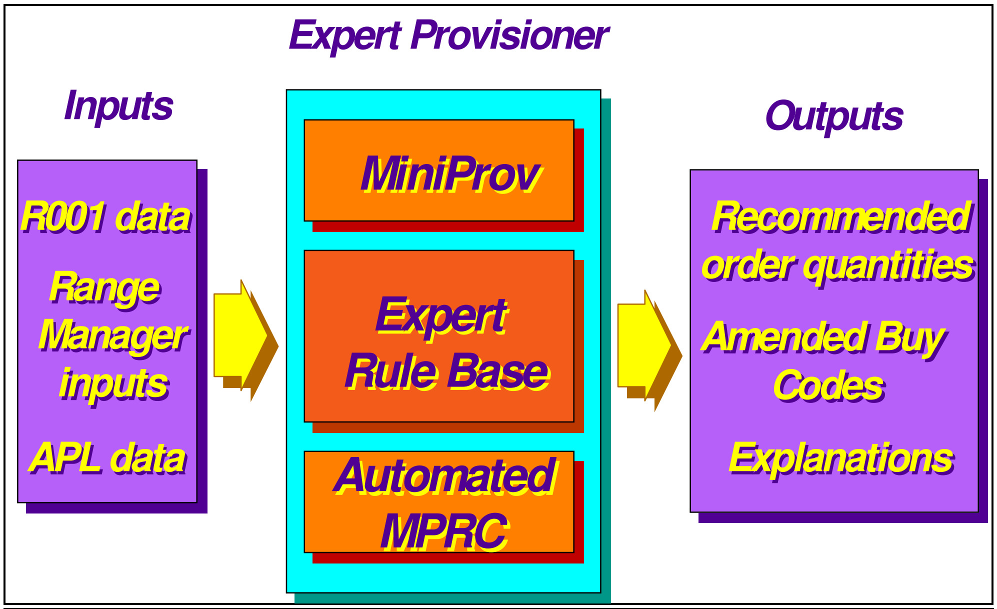

Figure 1 - Basic Components of the Expert Provisioner

Technical Specifications

The technical specifications for the prototype and the proposed production model are outlined below:

<u>The Expert Provisioner Prototype</u> A prototype of Expert Provisioner was developed to support Range Managers in provisioning consumable items for a single aircraft. The system runs on a standalone 486 PC with 8 megabytes of RAM and Windows 3.1. It uses AIAI's wxCLIPS package which encompasses the CLIPS rule-based programming language and the wxWindows package for developing form-based user interfaces. The electronic R001s and MPRCs are stored in Microsoft Access databases.

<u>The Expert Provisioner Production Model</u> The Expert Provisioner production model will initially be developed to handle consumable items for a group of Range Managers handling a subset of components for a single aircraft. The system will be required to run over a small network (10 PCs) which has a Fujitsu Team Server running ICL UnixWare v 2.2. The PCs connect to the network (running a TCP/IP protocol) using software called UWServer allowing them network file access (NFS) services. There is ample free disk space and the network traffic and node load is acceptable. Figure 2 shows the proposed hardware set up. Eventually, Expert Provisioner will be rolled out to hundreds of Range

Managers and its functionality will be expanded to include repairable items as well as consumables.

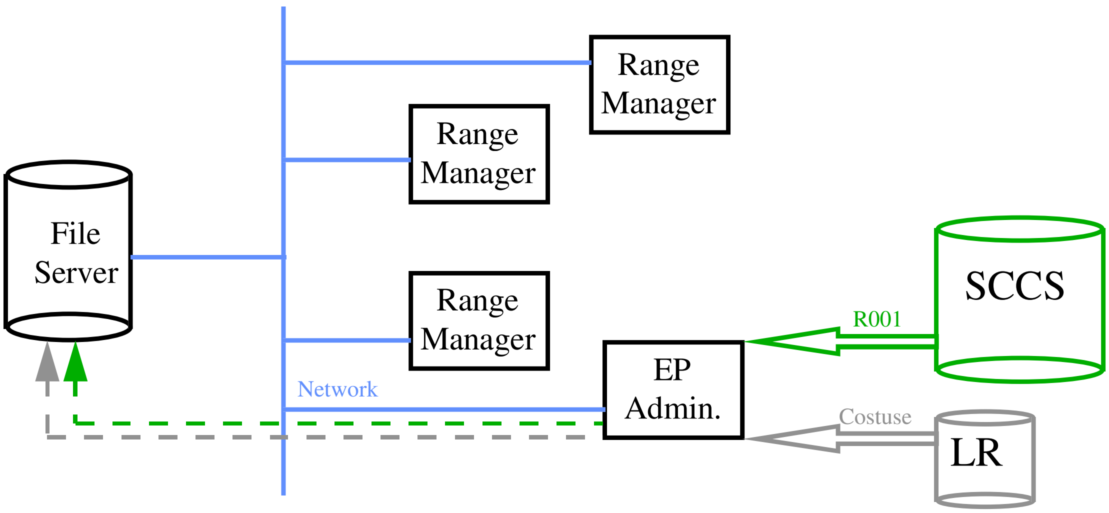

Figure 2 - Feasible Hardware Set-up

The system development was initially carried out using the CommonKADS methodology [Breuker & van de Velde, 1994]; the aim was to use acquired knowledge and to structure it using the CommonKADS multi-perspective modelling approach. A couple of knowledge acquisition interviews were carried out, and the resulting knowledge was structured into the domain, inference and task models which comprise CommonKADS' Expertise Model. It became apparent from this that:

- the expert knowledge lies in knowing what data on the form might indicate a problem, and what action to take if a problem is confirmed; the problem solving process is a repeated simple classification task, checking whether problems exist or not. Figure 3 describes the overall problem solving process using the inference structure diagrams recommended by CommonKADS.
- there was some structure in the domain knowledge (the various problems which the Range Managers check for could be categorised according to the source of the problem; see Figure 4 for an example), but the experienced Range Managers do not make use of any such categorisation during the checking process.
- the key knowledge about checks on problems and appropriate solutions could easily be represented in decision trees.

It was therefore decided to represent the details of acquired knowledge using decision trees, rather than in CommonKADS models. However, the structure observed in the domain models was initially used to partition the rule base and to ensure that the system checks all factors which could result in “nil buys” before running rules which might make small alterations to the recommended order quantity.

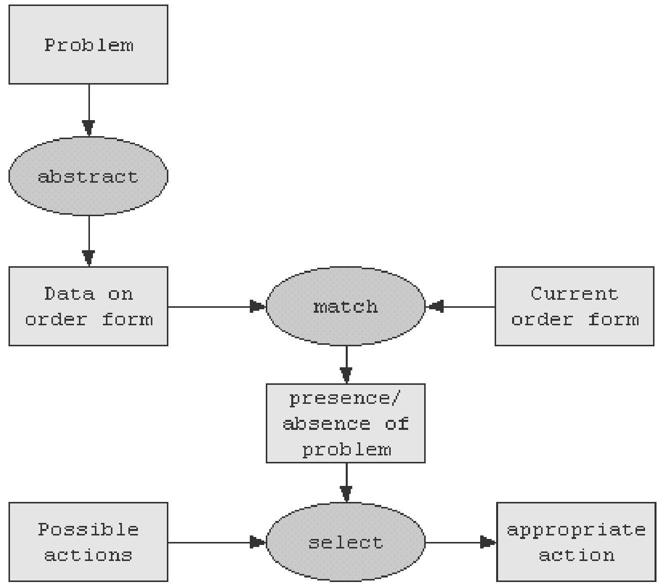

Figure 3: Inference structure for R001 (order form) assessment

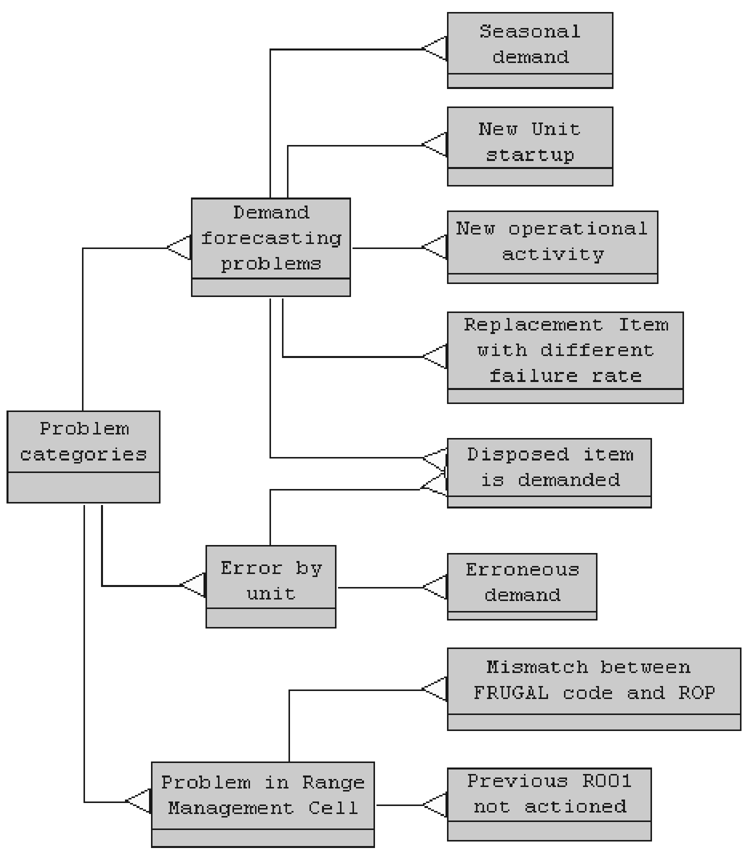

Figure 4: Example classification of problems in ordering

An example of a decision tree can be seen in Figure 5. This shows the processes required to determine the correct FRUGAL code for the R001. The FRUGAL code indicates whether the item is produced by British or French manufacturers, and whether it is for British or French use. Range Managers need to check that the lead time for delivery is consistent with the FRUGAL code, and that they are not processing an order for an item which should only be used by the other nationality.

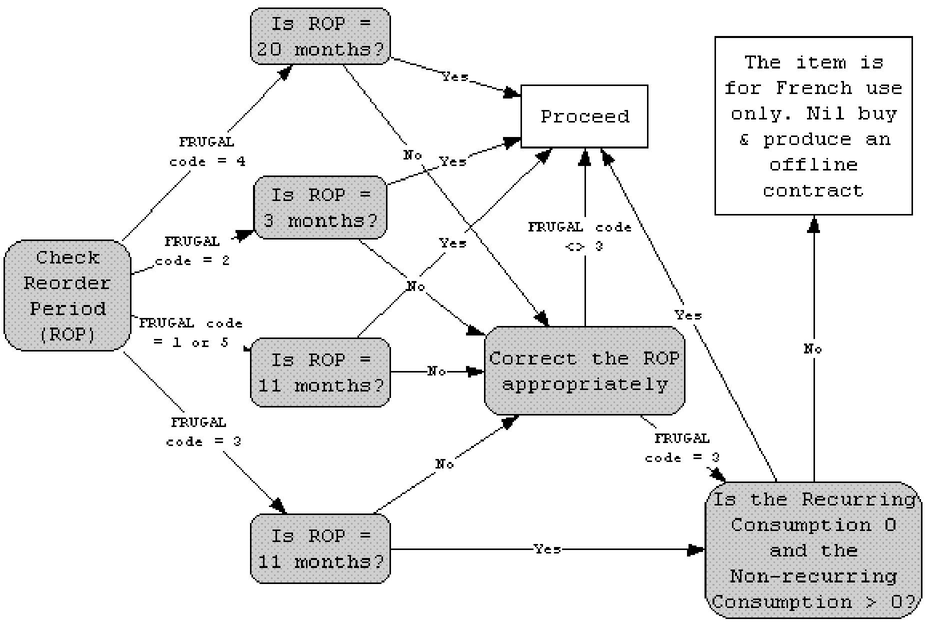

Figure 5: Decision tree for FRUGAL code checking

This decision tree was implemented within the system using a number of CLIPS rules; for a description of CLIPS syntax, see [Giarratano & Riley, 1989]. A (simplified) example of such a rule is given below. Note that add-a-list and advice-message are functions defined elsewhere in the system.

```
(defrule frugal-3-french
  (declare (salience ?*high-salience*))     ; rules that can produce nil buys have high priority
    (object
      (is-a R001)
      (recurring-demand $?recurring)        ; in CLIPS, a variable beginning with $? matches
                                            ; multiple values
      (non-recurring-demand $?non-recurring)
      (niin ?niin)                          ; the NIIN is a unique reference number for each part
    )
    (object
          (is-a mprc)
          (frugal-code 3)
          (niin ?niin)                      ; the MPRC is matched to an R001 by pattern
    )                                       ; matching on the NIIN
    (test (and (eq (add-a-list $?recurring) 0)
```

```
                (>  (add-a-list $?non-recurring) 0)))
=>
(advice-message
        "RULE:  Check for French use item.

This is a French-use only item!

Nil buy the current R001 and prepare an off-line contract.  Send a signal to the French detailing
the actions taken and listing the outside contract details that you have negotiated.")
)
```

Application Building

In February 1996, the RAF's Logistics Research group (LR) was given a mandate to investigate KBS technology to see if any of the techniques could be used to solve current Logistic problems. The RAF team consisted of two officers who had no previous experience of this technology, and were not programmers. The investigation was conducted in two phases. The first phase involved classroom training from AIAI at Edinburgh University who specialise in applications utilising this technology. During this initial phase, the two LR officers received an introduction to artificial intelligence, a review of KBS applications, an overview of KBS development tools, training in knowledge acquisition techniques, and hands on KBS programming training. The first phase of training was concluded in November 1996.

Midway through the first phase of training, LR personnel, with the assistance of AIAI, evaluated four actual RAF logistics problems which were nominated by various RAF departments as candidate problems for solution via a prototype KBS. From those candidates, it was determined that the Range Management re-provisioning decision process was best suited for a KBS solution. The development of a prototype KBS called "Expert Provisioner" constituted the second phase of training. There were two purposes for developing a KBS prototype. The first was to provide the LR trainees with an opportunity to put the classroom training into practice. The second was to produce a prototype product for demonstration to RAF logistics decision makers who would then decide whether the application of KBS technology appeared to have merit for further development and application in the logistics arena.

The development was split between AIAI and LR. LR interviewed the Range Managers concerned, consulted other experts, documents and generally conducted the knowledge acquisition process required to ascertain user requirements and the business knowledge necessary to build the rule base. AIAI wrote the rules and developed the interface between the various 'modules' that make up the Expert Provisioner prototype system. The prototype was completed during the second week of April 1997 for a total development cost of £55,000 pounds. The prototype was demonstrated on seven occasions in April/May 1997 to over 300 logistic personnel - from Range Managers to their senior management teams. The prototype was very favourably received and was deemed to have demonstrated the potential benefits of using KBS technology. As a result of this, LR have been tasked with producing a production model of the Expert Provisioner.

Initially, the production model will be developed for a single branch. It will be a networked version of the prototype with an expanded rule base and more sophisticated management functions. Further knowledge acquisition will be carried out to establish the rules that are required in the whole of this branch (the prototype rules accommodated part of the same branch). The database and interface software will be developed in the next few months after the knowledge acquisition stage has been completed and it is hoped that the initial production model will be rolled out and tested within 6 months of the start of the project. The users will be fully involved in both the knowledge acquisition and testing phases of the development. Expert Provisioner will be installed on the users existing network and very little training will be required. All the Range Managers involved in the initial branch have the requisite keyboard skills, and experience has shown that the operation of Expert Provisioner is easy to learn. There will however be changes to working practices (such as ensuring work is formally backed up) which will have to be fully investigated before ‘going live’, and the users will have to be informed and trained in these new practices.

The R001 data will be received electronically from the central computer system and distributed to the Range Managers via server links. Back up procedures will be introduced and archiving procedures developed according to each branch’s policy. Any changes that occur in the business data and hence the rules, or changes to the requirements will be referred back to LR who will undertake the maintenance of the program in the short term. In the long term, when Expert Provisioner has spread throughout the many branches, a dedicated team of fully trained personnel will be appointed. The day to day business of the RAF has changed immensely in the last few years, and will continue to do so for a long time to come. This is an important point which further demonstrates the suitability of KBS technology for this application. Any system introduced must be flexible and the modular design of Expert Provisioner will not only allow the rule base to be changed easily, but will allow the integration of additional modules with the base system. The rule base will evolve with every branch having ‘core’ or ‘common’ rules that they all share and ‘branch specific’ rules that apply only to specific branches. Additional rules can be added for any change or addition to the business and will only ‘fire’ when the particular event or series of events that triggers it occur.

Application Benefits

There were 4 potential benefits identified before the prototype was developed. The prototype has demonstrated how all these benefits will be realised. The benefits identified were:

- Improve the speed and accuracy of the data checking

  The Expert Provisioner prototype certainly showed that having all the required data in one place and passing the R001 data through a rule base to check for anomalies saved time and allowed the RM to concentrate on more productive areas of the job. For example, the rule base detects increases or decreases in demand and offers the appropriate advice.

- Improving the accuracy of the order quantity calculation

  The prototype will automatically recalculate an order quantity if parameters change (using the new parameters), applying all the current algorithms and rules pertaining. It will prompt to get the latest price and demand figures in order to use them in the order calculation and inform the RM if the quantity ordered is likely to leave items on the shelf after their "expiry date".

- Use as a training aid - Capture of expert knowledge

  This is perhaps the most productive use of this application. Whilst demonstrating the prototype EP, it was this feature that attracted the most attention. It will enable trainee Range Managers to make better decisions by leading them through the problem. The expert knowledge has been captured and can be accessed by trainees or experienced Range Managers at any time. It will allow trainees to be trained on systems that look and react like the live system and the audit log facility will allow trainees to work on real life problems (albeit old ones) and compare their results with the experts.

- Automatically records provisioning history data for use in Financial Management/Analysis

  The program automatically records historical provisioning data and Branch managers will be able to pull all the results from all their Range Managers to a central point and derive financial summaries much more easily and accurately than in the past. The automatic recording of the committed orders on the electronic MPRC has been demonstrated and will significantly reduce the time currently spent manually recording orders and details on the paper MPRC.

All the above benefits have been shown to the potential users and demonstrated with the prototype and will be further developed on the production model. The prototype has been trialled by a limited number of users but over 300 users have attended the Expert Provisioner prototype demonstration and provided very positive feed-back on the features demonstrated.

The long term benefits to the RAF supply system will be a more manageable inventory of stock items, a permanent base of expert knowledge, a system that can train and update its trainees much more efficiently and a more effective financial control system with full visibility of all assets. These benefits will grow in importance as Expert Provisioner is rolled out to other branches and enhanced to accommodate repairable stock items.

Conclusion

The Expert Provisioner assists RAF Range Managers in making accurate ordering decisions. It is a classic "expert system", in that it encodes the expertise of the most experienced Range Managers and makes the expertise available to the less experienced. The task (classification) is not technically difficult, and yet the system is capable of saving large amounts of money in reduced wastage and reduced storage costs. One of the most significant system benefits is that of on-line training, both initial training (by seeing realistic decisions being made on real data) and on-the-job training (by providing explanations of decisions made).

The system development was phased, in order to reduce risk by developing and evaluating a prototype before committing to a full system. The system development also included a training program in order to facilitate technology transfer from AIAI to the RAF Logistics Research personnel. The prototype has achieved its potential, and a production version of the system is now under development. It is anticipated that the approach to knowledge acquisition which was used for the prototype can be re-used to acquire knowledge from other Range Managers, such as those who work with repairable parts.

References

[Breuker & van de Velde, 1994] Breuker, J. and W. van de Velde, *The CommonKADS Library*. IOS Press, 1994.

[Giarratano & Riley, 1989] Giarratano, J. and G. Riley, *Expert Systems: Principles and Programming*. PWS-Kent, 1989.