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University of Southampton

The Design and Evaluation of Industrial Hypermedia.

By

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ABSTRACT

Faculty of Engineering and Applied Science

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The Design and Evaluation of Industrial Hypermedia.

By Gary Brian Wills

This thesis proposes design, authoring and evaluation methodologies to address the issues faced by an enterprise when developing a large-scale industrial strength hypermedia application, for use in a manufacturing environment.

The design methodology satisfies the requirements found in the industrial environment in a holistic approach. That is, the methodology takes into account the information structures, the constraints that exist within the industrial environment, and the background of the people who will have to implement the hypermedia application. The size and complexity of an industrial environment aggravates the problems found in general hypermedia authoring, especially in the areas of scalability, re-use and cognitive overload to the author. Hence, an authoring methodology is present, which addresses these issues.

The design and authoring methodologies are evaluated against an independent set of criteria. The results show, even after sensitivity analysis, that when compared against other methodologies, the methodologies presented in this thesis are the ones better suited to meet the requirements of an industrial application.

The design and authoring methodologies have been used to produce an industrial hypermedia application. The application communicated with existing information systems, factory floor equipment and the management network. The application has been used to evaluate the usability of the system within the factory environment.

A cost effective user evaluation methodology was developed. Not only did it allow potential problems to be identified early in the project, but it also encouraged ownership of the project from the managers, maintainers and factory-floor operators. The user evaluation showed that, compared to an existing paper based system, the user preferred the hypermedia system and that they found the hypermedia application quicker and easier to use.

While the majority of problems to be overcome, when introducing industrial strength hypermedia, are technical, some of the most difficult issues relate to the inertia of the management culture within the organisation. Hence, the strategic benefits and considerations when introducing hypermedia application into an organisation are discussed. In addition a model for estimating the effort to produce an industrial hypermedia application, has been developed.

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Chapter 1.

Introduction.

A considerable amount of information is required to operate and maintain a complex manufacturing system. As products and system increase in sophistication and complexity, both using and managing the vast amount of documentation generated to provide operational instructions or technical information for maintenance is becoming an increasingly pressing issue. This, together with the increased requirement for information to be shared accurately between design, sales, procurement and manufacturing facilities, makes the management of information resources vital to the success of any company.

The documentation concerned with a manufacturing system ranges from a few hundred pages for a medium sized industrial machine tool, to many thousands of individual manuals for a complete manufacturing plant. Hence, maintenance or repair work in the event of a system failure, can be time-critical [HSU 99]. As equipment, plant and systems are replaced or modernised, many of the old paper-based information systems are being substituted with electronic document management systems. This often creates a sprawling information-space consisting of electronic documents that are frequently isolated from each other.

The challenge is to develop an information system that is both comprehensive and will satisfy the increasing demand from the industrial environment for up-to-date and easily accessible information. To resolve this challenge the use of information technology is being applied to factory floor activities and can range from computer controlled systems

with electronic help facilities, to fully integrated electronic document management systems. As the volume of available electronic information increases, managing the information and ensuring that the user can access the information quickly and effectively becomes a critical issue.

In order to reduce cost within manufacturing, it is common practice to produce products of the same family using common subassemblies or piece-part components. Hence, a significant amount of the information relating to these items can be reused. In addition, technical documentation is frequently highly cross-referenced, often with many types of documents which can be in different formats. The process of locating information then becomes time-consuming, frustrating users as they open and close an application looking for essential information. Conventional information techniques are not sufficient to satisfy these requirements [Marinheiro 98].

A hypermedia system allows associations to be made between information in different media in a manner similar to that naturally undertaken by people. Previous work has demonstrated how a hypermedia system can overcome some of the common problems with traditional computer- or paper-based systems which present and distribute text and engineering drawings sequentially [Crowder 96c].

The concept and requirements for industrial strength hypermedia were initially presented by Malcolm et al [Malcolm 91]. Due to the increase in globalisation, virtual enterprises, lean and agile manufacturing, the demands for correct and easily accessible information have not abated. Crowder et al have demonstrated that by using an open hypermedia system, a single information resource base can be used for operator training, planned maintenance and diagnostics of a single machine [Crowder 96b].

For any information system to be successfully introduced into all areas of a manufacturing plant, the information management strategy must enable the integration of information resources of different formats. It must also allow personnel from different levels of the organisation, with different and varying computer skills, effective and controlled access to the required information. In addition, the integrity of the information must be maintained by the implementation of suitable change control and associated security measures.

Hence, it is essential that the hypermedia application be evaluated using the appropriate end-users.

In practice, it must be recognised that while the majority of problems to be overcome, are technical, some of the most difficult problems relate to the inertia of the management culture within the organisation. The introduction of industrial strength hypermedia requires a paradigm shift; from the paper document paradigm to the electronic. Hence, the drivers and enablers for such a shift need to be understood and, as cost is an intrinsic component to many management decisions, the effort and cost associated with producing an industrial hypermedia application needs to be investigated.

In this research programme a methodology for the design, authoring and implementation of a factory-wide hypermedia application is developed. A holistic approach is taken to the management and navigation of the growing information space in the industrial environment.

1.1 Definitions.

Within this thesis, the term hypermedia system is applied to a system in which the concepts of hypertext are applied to multimedia data.

For this research, the term *industrial hypermedia application* is used to represent the overall collection of documents in an industrial multimedia information space, the associations made using hyperlinks, and the processes that enable links to be followed and information retrieved.

Hypermedia authoring can be confused with the physical process of a person writing a book, manual or procedure. However, within the hypertext community, hypermedia authoring is normally taken to be the process, by which the associations between pieces of information are made, using hyperlinks. It is in this context that *authoring* is used in this thesis.

1.2 Open Hypermedia.

The term hypertext was first proposed by Ted Nelson in the late 1960s [Conklin 87].

Nelson applied it to unstructured text, where associations between the text were made with

links. In practice, hypermedia is similar to hypertext but, rather than use text files, hypermedia allows associations to be made between different types of media.

Many hypermedia applications embed links into the structure of the document and often require the documents to be converted to a proprietary format, leading to problems in maintainability of the application [Goose 97]. In contrast, an open hypermedia system can be defined as follows [Davis 94, Fountain 90]:

- A system which does not impose any mark-up upon the data that will prevent the data from being accessible to other processes that do not belong to the system.
- There is a separation of links from data objects.
- A system that can integrate with any tool that runs under the host operating system.
- A system in which data and processes may be distributed across a network and across hardware platforms.
- A system in which there is no artificial distinction between readers and authors.
- A system in which it is possible to easily add new functionality.

Within the open hypermedia philosophy, the hypermedia links are themselves a valuable store of knowledge. If this knowledge is bound too tightly to the documents, then it cannot be applied to new data. No information about the links is held in the document data files in the form of mark-up. Instead, all data files remain in the native format of the application that created them, whilst the link information is held in link databases (linkbases).

Research into open hypermedia has been undertaken at the University of Southampton since 1989 [Fountain 90]. This has resulted in the development of a commercial software package, called Microcosm Plus [Multicosm], which has been generally entitled Microcosm in the remainder of the thesis.

Microcosm consists of a number of autonomous processes, which communicate with each other by a message-passing system [Heath 94]. Due to its open architecture, Microcosm allows documents produced by different applications to be linked together while still in their native format [Davis 92a].

The basic processes in Microcosm are the filters and viewers, shown in Figure 1-1, [Heath 94, Multicosm]. The viewers are programs that allow the user to view documents in their

native format, and onto which the links are overlaid. One viewer is running for each document visible, and different types of viewers are used for different types of document or medium. The task of the viewer is to allow the user to read the document, to make selections and to choose actions. The viewer is responsible for binding the interaction of the user and document into a message. Document viewers communicate by means of messages, and all messages are routed through the Document Control System.

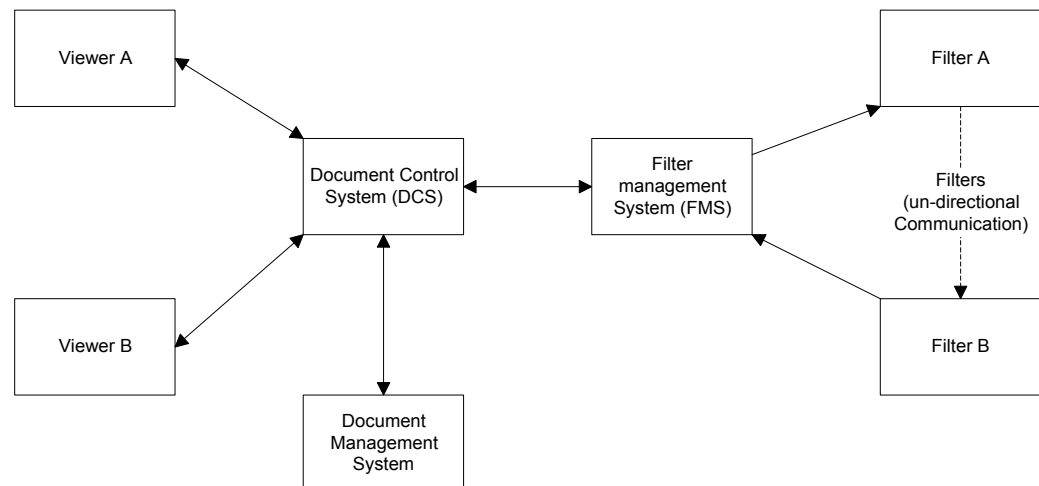


Figure 1-1 The Diagrammatic representation of the Microcosm Model [Heath 94]

The Document Control System opens documents, routes messages, supports links and connects to external applications that are not part of the Microcosm system, for example spreadsheets, databases etc. When the Document Control System receives a message it processes it according to the action. Each action has a task associated with it, and the task will be started up and send the required message. The Document Control System passes the message from the document viewer onto the Filter Manager.

The Filter Manager sends the message to each of the filters in turn, where the Filter Manager will look for one or more processes that can satisfy this request. Filters are processes that are responsible for receiving message, taking any appropriate actions, and then handling the message on the next filter in the chain, via the Filter Manager. The user can control the order in which the filters appear in the chain. Filters may be installed and removed in order to configure the system according to the user's preference.

A linkbase holds all the information referring to a particular set of links. A linkbase is classed as a filter in Microcosm, and as such, resides in the filter chain. In Microcosm Linkbases are flat text files with one record per link, containing the source and destination information. More than one linkbase may be installed at a time, making it possible to provide different views of the information. Also linkbases can be allocated to an individual or group to make links that are not visible in the public system. Each record in the linkbase associates a link message with a dispatch message. If a match is found, then the dispatch message is sent back to the Document Control System. The message contains the name of the target document and the offset from the top of the document. This information is used to start up a document viewer of the appropriate type, load the target document, and move to the specified location within the document.

Microcosm's Document Management System (DMS) maintains data about the documents known to Microcosm, including various attributes of these documents, and points to where they may be found. The actual documents remain on the original storage medium that they were on when they were registered with the DMS. The DMS provides two classes of service: firstly it provides a safe method for moving the physical position of documents without having to change all the linkbases; secondly it provides a method for accessing documents by their attributes.

The DMS holds the information on the documents in its Docuverse, a flat text file. Typical attributes are; description of the file, the full filename, the physical location on the storage media, the Microcosm logical types of the document, the author, descriptive keywords, and the document's unique ID. In addition, users can define their own attributes. This enables extra functionality to be added.

1.3 Declaration.

The work in this thesis was in part undertaken within an EPSRC (Engineering and Physical Science Research Council) funded Factory Information Resource Management (FIRM) project [Crowder 96a], grant number GR/L/10482.

This thesis discusses the author's own work, with the exception of part of chapter 5 which presents the authoring environment and link clusters.

1.4 Thesis Structure.

The research reported in this thesis considers the design and evaluation of hypermedia applications for use in an industrial environment. This was achieved by the development of enhanced design and authoring methodologies, while addressing the issues faced by an enterprise when developing a large-scale industrial hypermedia application.

The prime industrial collaborator for this research was Pirelli Cables based at Eastleigh. To ensure that the concepts developed are generic, the Ford Motor Company at Swaythling was also used. Both organisations are large industrial manufacturers with complex plant, yet they make dissimilar products.

It is necessary to understand the general philosophies governing the working environment in which the application is to be used, and chapter 2 discusses the control of documentation and the information systems used in a manufacturing enterprise. To ensure that the hypermedia application is applicable to the specific environment in which the evaluation is to take place, a contextual review of the working practices was undertaken. The results are also presented in chapter 2.

There are a number of suggested hypermedia design methodologies published in the literature. These are reviewed in chapter 3 and application to industrial hypermedia examined. Based on this review, a design methodology applicable to the requirements of an industrial hypermedia application is presented in chapter 3.

Although authoring a hypermedia system is an integral part of the overall design process, it is also a separate process in its own right and is examined in greater depth in chapter 4. A methodology for authoring in an industrial environment is presented, following a review of current published strategies.

While the design and authoring methodologies are generic, the hypermedia application produced is specific to the target industrial system. The hypermedia application developed under FIRM project is described in chapter 5. In addition, the methodologies used to produce the case study hypermedia application are compared against existing methodologies, to answer the question, 'could another existing methodology have satisfied the requirements for industrial strength hypermedia applications'?

The widespread introduction of hypermedia into an industrial environment is, to a large extent, governed by its acceptance by factory floor personnel. Hence, the need for evaluation of the effectiveness of the Human-Computer-Interaction (HCI) within the factory environment, along with the design of the user interface and navigational aids. The general issues and methods applied to the evaluation of industrial hypermedia are explored in Chapter 6, and section 6.4 describes the methodology specifically used to evaluate a large-scale industrial hypermedia application. The results from the user trials using the structured expert review method are reported in chapter 7, and the evaluation results of the factory-floor evaluation are reported in chapter 8.

Chapter 9 examines the strategic benefits and considerations when introducing industrial strength hypermedia. An effort and cost model for the authoring process is also presented.

Chapter 10 presents the conclusions of the research and proposes some future research within industrial strength hypermedia.

Chapter 2.

Industrial Information Environments.

The chapter starts with a description of the case study and its information space. Included in this description, is the original method of delivering information to the factory floor at Pirelli, the results from a contextual review and a discussion on how industrial strength hypermedia should aid effective retrieval of information. This chapter then briefly examines the general procedures used to control and issue factory-floor documentation in the UK manufacturing industry, focusing on effective paper based systems and information for efficient maintenance. The chapter concludes with an overview of other information systems found on the factory floor.

2.1 The Case Study Environment.

The case study for this research was the Supertension Sheathing Process Line, which is part of the Supertension Cable manufacturing area at Pirelli Cables, Eastleigh, Hampshire. The Supertension Process Line, at the start of this research, had just finished being commissioned after a major refurbishment and offered the opportunity to obtain information in electronic format from the Original Equipment Manufacturers (OEMs).

The Supertension Sheathing Line, see Figure 2-1, was supplied as a turnkey system by Nokia-Maillefer. The line incorporates a large number of third party systems, including the cable stands provided by Stolberger, drives supplied by Eurotherm Drives and a PLC supplied by Siemens Automation. The production line consists of twelve major components (see Figure 2-2).

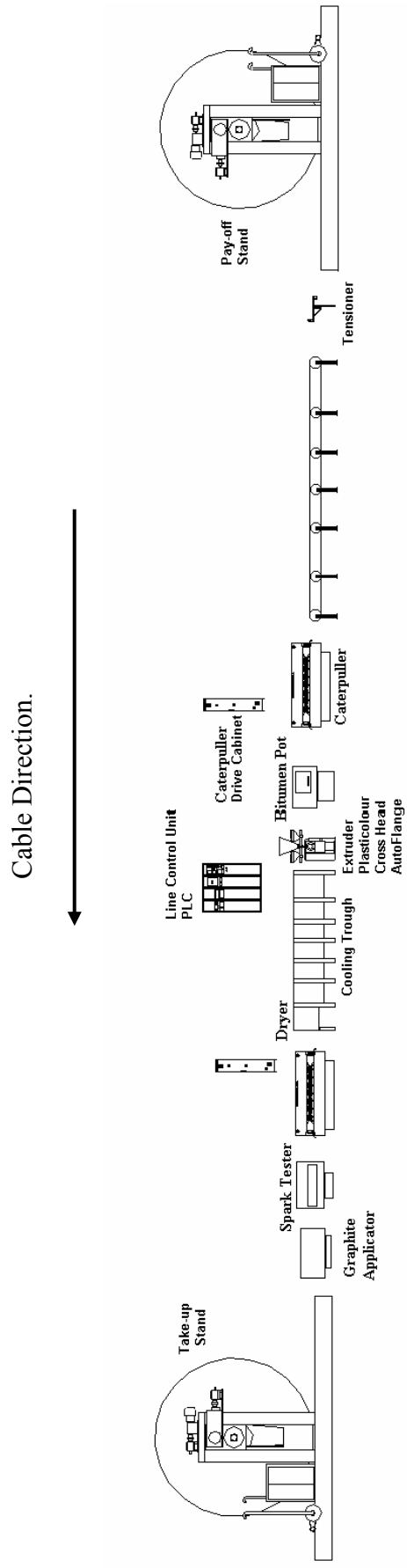


Figure 2-1 Diagram of the Supertension Sheathing Line.

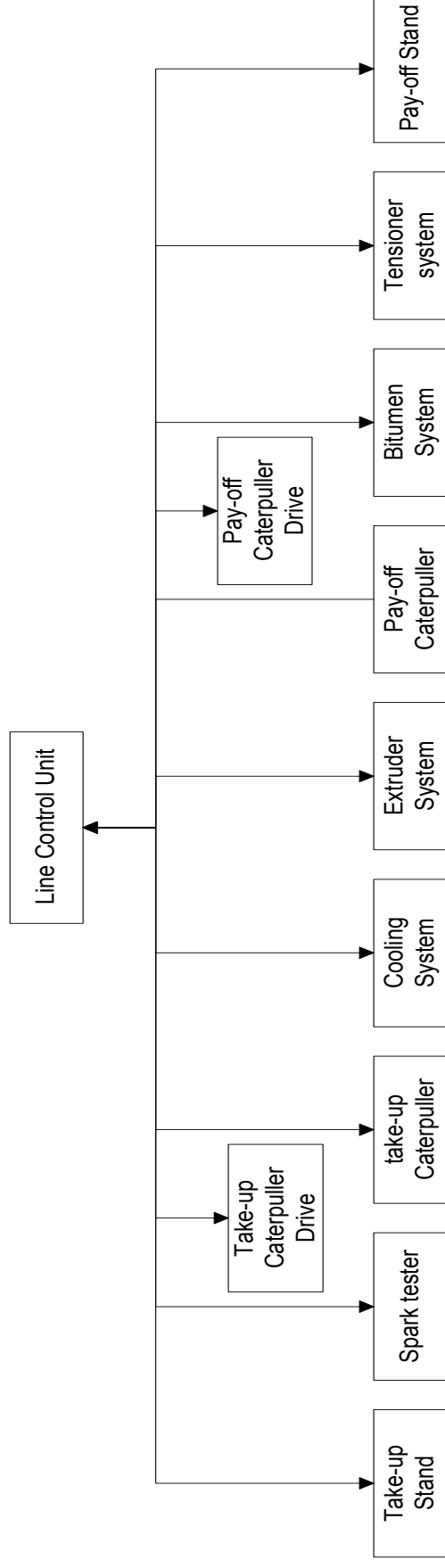


Figure 2-2 Block Diagram of the Supertension line.

The Supertension Sheathing line pulls uncoated cable off the pay-off stand through six different processes and on to the take-up reel. A bitumen coating is extruded directly onto the cable or onto the aluminium sheath (in the case of oil filled cables). Then a cross-linked polyethylene outer-sheath is extruded onto the bitumen-coated cable see Figure 2-3. After cooling in several tanks of circulating water, the cable is passing through a dryer to remove excess water. It is then spark tested for any defects in the insulation. A thin graphite coating is then placed onto the outer sheath for further testing purposes. This acts as an earth, relieving the electrical stress in the insulation during testing. The pay-off and take-up stands can take cable drums up to 50 tonnes with a maximum cable diameter of 155 mm, and weight of 40-50 kg m⁻¹. The process line is approximately 90 meters in length, the tallest components are the pay-off and take-up which are approximately 5.5 meters in height, as shown Figure 2-4.

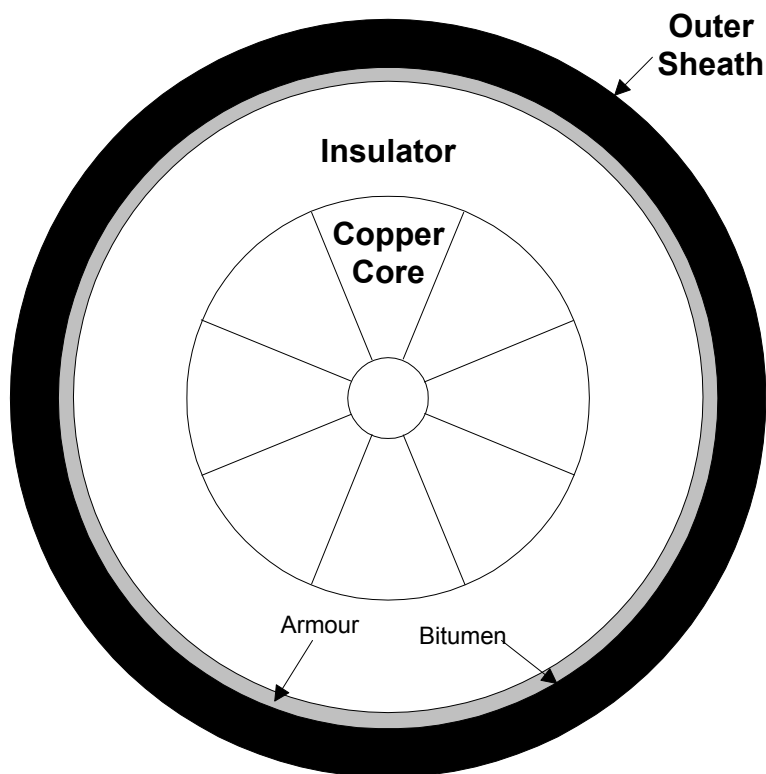


Figure 2-3 Cross section of a typical cable.



Figure 2-4 The Pay-off Stand.

The overall system is controlled via a Programmable Logic Controller (PLC). There are individual control panels for each of the separate processes. These are only used during set-up and emergency shut down, where the PLC is bypassed. The states of the main process line parameters are displayed on a terminal and can be modified via the PLC. The PLC also monitors alarm circuits of the major components and flags any alarms to the operator.

Information from the main contractors, Nokia-Maillefer, represented approximately fifty percent of the information for the process line equipment. Table 2-1, gives a breakdown of the information for the case study hypermedia application.

Company	Status	System	Information	Original Media
Pirelli Cables	Customer	Users	Forms, Training documents, Technical instruction, Check lists, Drawings, Material lists	Word Documents, Video, Bitmaps, Microfiche, Paper Documents, paper Drawings, Spreadsheets
Nokia-Maillefer	Prime-Contractor	System Integrators	Integration Information, manuals and Drawings	Word Documents, AutoCAD Drawings, Bitmaps, Paper Documents
Eurotherm	OEM	Drive units and Temperature controllers	Operating and Maintenance Manuals	Word Documents, Bitmaps, AutoCAD Drawings, Paper Manual and drawings
Siemens	OEM	PLC and Motors	Operating and Maintenance Manuals	PDF Documents, Paper Manual and drawings
Santasalo,	OEM	Gear box	Maintenance Manuals	Paper Manual and drawings
Bywater	OEM	Dryers and cooling systems	No information incorporated	
Stolberger	Sub-Contractor	Take-up and Pay-off Stands		

Table 2-1 Information Sources used in the case study application.

2.2 Contextual Review of the Information Domain.

An industrial environment will generally have a large established information space. Therefore, a hypermedia system should not aim to replace these existing information systems but to incorporate them, thereby ensuring that all essential information is included in the hypermedia application.

In an industrial environment the structure of the information is generally hierarchical and will often relate to physical objects, see Figure 2-5. The same piece of information can be used within an organisation by various people, from different departments carrying out dissimilar tasks. In most industrial environments the structure of the information is defined by:

- The structure of the organisation.
- The job description of the person using the information.
- The layout and use of equipment, process lines, manufacturing cells, etc.

Any developed hypermedia application should be relevant and specific to the application domain in which it is to be used. Therefore, in order to produce an industrial application it is essential that the current work practices and documentation structures, together with how they effect the content of the application, should be clearly understood. To achieve this, a detailed audit of the information structure and working practices, using the contextual inquiry method [Preece 94] at the Supertension Sheathing Line at Pirelli Cables, Eastleigh was made (see Appendix A for detailed results). A shorter audit was carried out at Ford Motor Company, Swaythling.

Contextual inquiry is a method that comes under the general heading of interpretative evaluation. It is used in the collecting and analysing of data on how people use technology in their natural situations. The rationale behind this type of evaluation method is that the working environment and practical tasks required of the user will effect their behaviour. Contextual enquiry is used to aid the developers of the hypermedia application in understanding the working environment, to uncover hidden work practices, and to spotting implicit work practices, etc.

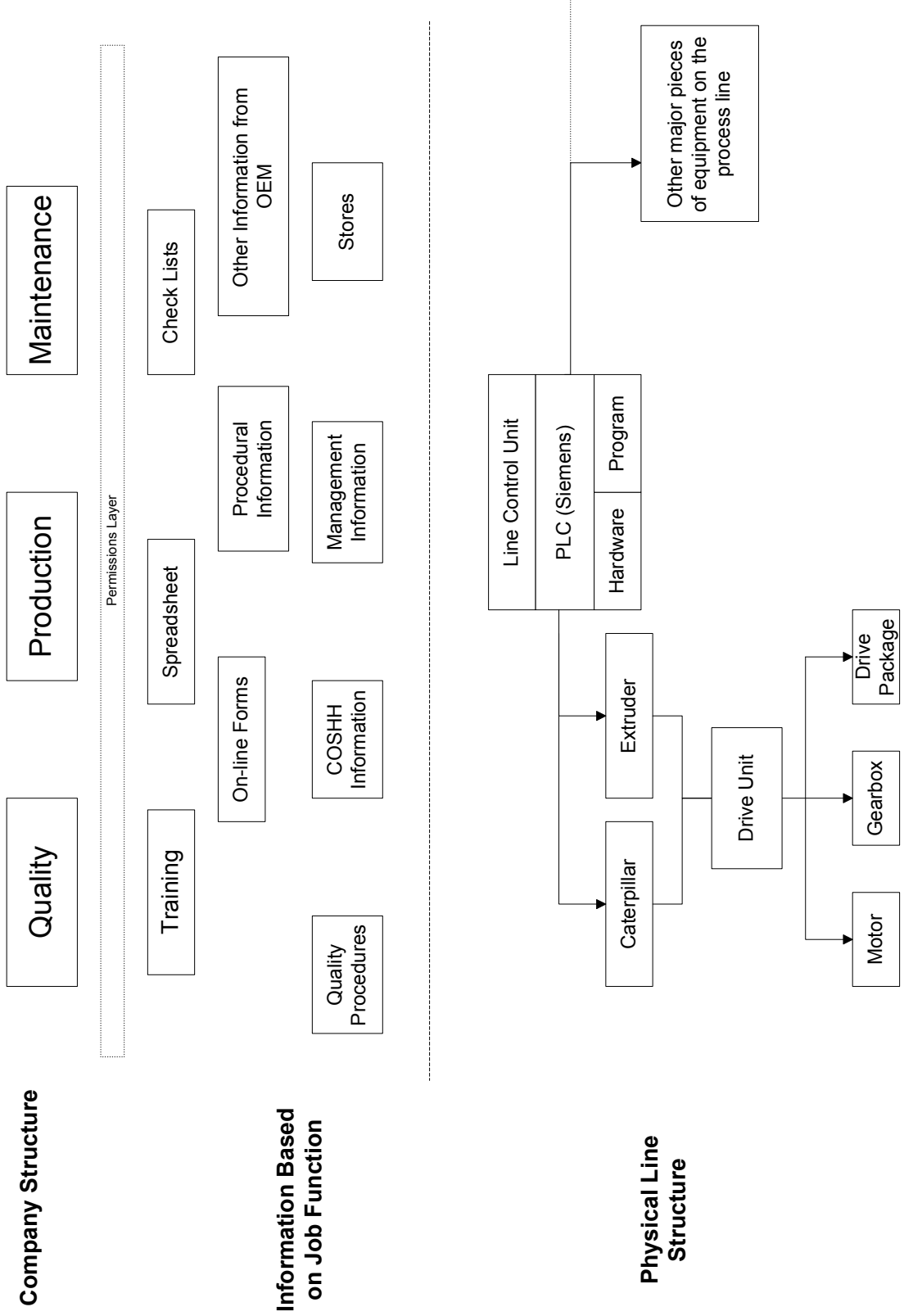


Figure 2-5 The information space for the process line at Pirelli Cables

The items of interest for the researcher carrying out an interpretative evaluation are the:

- Structure and language used in the work.
- Individual and group actions and intentions.
- The culture affecting the work.
- Explicit and implicit aspects of the work.

2.2.1 Comments on the Contextual Review.

Both Pirelli and Ford operate a continuous improvement scheme and have BS EN ISO 9001 approval. However, the contextual inquiry revealed that there was a fragmented information system operating within the Pirelli Eastleigh site, with many documents being reproduced for use around the site. Although the documents were issued and amended in a controlled manner, they were not always easily accessible to the personnel who required them. Therefore, the introduction of an integrated hypermedia information system onto the factory floor at Pirelli would bring the following advantages:

- Access to information from any point in the factory environment.
- Easier cross-referencing.
- Remove the burden of having to produce controlled copies.
- Ensure that the operators and maintainers have access to most recent information at all times.
- Provide additional useful information only when necessary, removing the current burden of superfluous paperwork for each maintenance operation.
- Help close the quality loop for many of the tasks performed by the operators. For example, with the weekly current checks, the results would be entered into the system along with the instrument number used to take the measurement. The system then processes the information. The system would inform the operator if the current readings were out of range, plot the control charts, allow traceability of calibrated equipment usage. etc.
- Pirelli, like Ford, had a problem in getting operators to write things down. That is, many of the factor-floor operators were unused to writing things down and hence felt insecure and threatened, when asked to write descriptions on forms for examination later. Having a system that will enable cut and paste with a spell checker may overcome some of these problems.

2.3 Delivery of the Information in a Factory Environment.

The general requirements for the physical system that will deliver the information are:

- That it is safe to operate in the factory environment.
- That it provides ease of use for all personnel in an industrial environment. This should not exclude users with disabilities (who use the present system) from using any new or replacement system.
- The system shall be portable and be usable in all relevant areas of the factory.

In addition, for the system to achieve the concept of a factory-wide information resource, the system needs to have [Crowder 96a]:

- The capability to communicate electronically transparently with other information sources as required.
- The ability to monitor production equipment, and use the system data as part of a diagnostic or maintenance process.
- The ability to present information to other departments (users), enabling them to carry out their function, for example the purchasing staff can view the materials required and the schedules of the planned work.

The factory floor is a hostile environment for any piece of office equipment, in particular computer-interfaces. Conventional cursor pointing devices suffer with the ingress of dirt, dust and grease, making them very quickly difficult to use. Industrial keyboards are designed to stop dust and dirt ingress, and have some success. However, they do not have any successful conventional cursor tracking systems.

The need for lightweight robust portable computers was a requirement for road maintenance teams [Hyman 95]. Hyman chose to perform a maintenance quality evaluation using a pen-based system. The greatest source of benefits was the ability to perform all the calculations and generate the reports on site. While key-based data entry was possible with the convertible computer, the inspectors preferred a portable pen-based system to carry with them during their site inspections. Operators needed very little training to use the equipment, and the handwriting recognition function of the equipment proved to be reliable. Similar benefits were found with an earlier research project at Pirelli Cables, Aberdare [Crowder 95a]. The Aberdare case study used a pen based portable computer, to deliver the information, with the hypermedia application held on the hard disk. The users found this easy and natural to use. To select a link, the user circled

the object on the screen, and by tapping the screen, were able to select a menu action. It is also possible to deliver the information to the maintenance personnel and still allow them to use both hands to carry out a task. This is achieved by using a lightweight wearable computer. This wearable computer is voice operated, with a flip down eyepiece to provide the user with a display, equivalent to a 14-inch monitor at approximately a metre [Colins]. However, for the portable computers, battery power is still a problem.

2.4 Control of Information in an Industrial Environment.

At present the majority of information within an industrial environment is stored and distributed via non-electronic means (i.e. paper, microfiche). Consequently, controls are placed on the issue, amendment and removal of these documents. It was therefore necessary to understand the control procedures that industry use for documentation control. Documentation control generally comes under quality assurance (QA) procedures, the most common being the ISO 9000 model [BSI 94].

The interpretation and implementation of the ISO 9000 requirement varies between organisations. Generally, the easiest way to write such a procedure is one based on a flow diagram of the movement of paper around the factory, stating the actions at each stage. This has the very large disadvantage that personnel have to read a great deal of superfluous information to ensure that they have not missed any vital information. Therefore, these types of procedures are rarely effective or followed. However this is very easy to audit, and this is an essential function in QA.

Alternatively, the procedures are written across the company structure, with individual departments having separate manuals. This ensures that personnel are clear about their responsibilities. The disadvantage is that the auditors need to understand the whole system and ensure that the system is coherent. General requirements for the documentation procedure revolve around the need to ensure the operator has the correct information at all times, and that managers are clear about their responsibilities.

2.4.1 Effective Paper Based Document Systems.

When designing a procedure based control system, it is very easy to start with a large number of procedures. These are usual refined through the normal auditing and review activities.

Due to the restructuring of their companies, British Rail [Lilleker 92] and London Underground [Vellacott 92] were forced to evaluate and reorganise their maintenance documentation. It is claimed that this resulted in a leaner and more effective paper-based maintenance documentation system. An efficient and effective non-electronic documentation system will simplify any implementation of an electronic system, such as industrial hypermedia. Some of the resulting good practices instigated by London Underground, and British Rail, are:

- Creation of procedure manuals that incorporate all the required repair instructions for a particular system in one book, with a discrete manual for each type of major piece of equipment and for similar types or versions.
- Long work instructions to be broken down into small sections, covering an identifiable component. Job descriptions start on a new page, facilitating quick updates.
- Including most of the procedural information into the work instructions reduced the initial number of procedures, so reducing the resources needed to produce the work instruction. This still required the specialist engineer to draft the core text, but removed the need for them to write the subsidiary sections.
- There was only one source document defining the standards of maintenance.
- The defined maintenance tasks were indexed by a zonal structure of the equipment.
- There is a standard format and structure of the information for different major pieces of equipment. This allows comparison of multi-equipment revision levels to be quickly executed. In addition, staff moving between different process lines need only learn new information and not the documentation structure.
- Well referenced documentation, enabling quick and easy location of information.
- A common task description to be used as much as possible (i.e. examine, check, inspect).

While these proved to be effective paper based systems, Crowder et al [Crowder 96] noted that conventional information retrieval techniques still suffered from:

- Introduction of errors due to constant cross-referencing between different information systems.
- On older equipment, the quality of factory floor documentation may be poor or incomplete.
- Distribution of documentation around the factory creates problems ensuring that all copies are at the correct issue.

- The inability to share information gained by experience, by other maintenance teams and personnel.

The use of hypermedia should overcome these problems and facilitate the authoring of the information. With hypermedia only one copy of a document is required. The use of templates allows similar documentation to be produced in a consistent manner and using hyperlinks allows quick and effective cross-referencing. In addition, a less obvious advantage of using hypermedia is that once the links are created, the process of ensuring cross-referencing of documents after an update is easier to maintain.

2.4.2 Information in the Maintenance Environment.

The end users of a factory floor information system, in the first instance, will be the operators and maintenance technicians on the shopfloor. Hence, this section describes the information required and the methods used to control the maintenance process.

Within any manufacturing organisation, there is a requirement for machines to be maintained in such a way as to sustain product quality and avoid breakdown.

Maintenance is defined as the combination of all technical and corresponding administrative actions intended to retain an item in, or restore it to, a state in which it can perform its required function. [BSI 87]. Reliability of manufacturing machine systems is crucial if the quality of the product is to persist. That is, the product is in the right place, at the right time, at the right price, in the right quantity and of the right quality. Maintenance is now considered such a fundamental underlying principle to product quality that it is explicitly included in ISO 9000 [BSI 94]. Yet to non-engineers, maintenance is seen as a necessary evil which absorbs an unacceptable proportion of expenditure [Clemenston 92].

Different manufacturing businesses require different approaches and therefore it is incorrect to assume that there is only one method of achieving best practice. Depending on the application it may be sufficient to maintain machinery on a 'fix it when bust' type approach, right through to using sophisticated condition monitoring methods to determine the time before failure [Parker 95]. Therefore, best practice is achieved by the most cost-effective method to support the manufacturing operation.

The cost of maintenance is more likely to be controlled in a climate of predictability [Clemenston 92]. This has been achieved in most part by pro-active maintenance, i.e. condition monitoring; good administration and planning of maintenance; just-in-time

spares, etc. To reduce cost further, a change within industrial plants to multi-skilling of maintenance and operational personnel is taking place [Crowder 95b], resulting in the requirement for accurate and up to date information.

The control of maintenance in the workshop is a carefully planned and organised process. An effective structure will enable extensive use of information technology, improve quality and reduce costs [Levy 92]. In order that maintenance personnel are able to work to a maintenance schedule, the instructions within it must be clear, concise and unambiguous [Lilleker 92]. A maintenance control system should clearly identify what work is to be undertaken and when, the materials and any requirements for special tools [Niebel 85]. Hence, the system requires information from various other departments.

However, careful planning is not enough, as every facet of maintenance activity relies on the skills of the technician performing the task. The operators and maintainers have vital experience and are effective real-time monitors of the machine and product quality. Therefore, their knowledge should be fully utilised in the application of maintenance [Clemenston 92].

Scheduled Maintenance is sometimes differentiated from other scheduled tasks, such as lubricating or adjustment, as these are performed to sustain operations. This differentiation is utilised in Total Production Maintenance (TPM), where factory floor operators carry out the lubricating, adjusting and cleaning of the equipment. This then leaves the maintenance technician to carry out more sophisticated maintenance tasks, i.e. vibration analysis, oil sample analysis, etc [Parker 95, Davis 92b]. The information that once was only viewed by maintenance is required to be shared between departments, in such a way as not to burden the operator with superfluous information.

Preventative maintenance has and is being used to reduce product defects, resulting from machine unreliability. However, it has been suggested that only condition-based monitoring aims to achieve the goal of zero defects. A Condition Monitoring (CM) system is essentially a system that relies on information or data obtained from the product quality or the process parameters. One of the major hurdles to introducing an effective CM system is that information is usually held on different departmental databases. For example, machine analysis/fault diagnoses is held by the maintenance function, whereas product quality monitoring is held by the quality/product control functions. Therefore a

mechanism is required to link the information held within databases, and allow the user (with the correct permissions) to move seamlessly between the databases [Drake 92].

2.5 Related Information systems.

This section briefly describes information systems and standards that are currently influencing the factory-floor information provision.

2.5.1 SAP

SAP (Systems, Applications and Products in Data Processing) is the registered trademark of a German software company that is one of many companies that specialises in providing client/server business applications, for enterprise resource planning [SAP]. The latest version, referred to as R/3, is based on the concept of combining all the business activities and technical processes of a company into a single, integrated software solution [IBM]. Its applications cover a wide variety of areas, including financial, asset management, project planning, sales and distribution, manufacturing, production planning, quality assurance, and human resources. SAP is an open modular system that can integrate resources across the Internet, and it can even use a Web browser as a user interface. SAP uses an extensive library of predefined business processes for each of functional software requirement. While this type of application is very good at managing the flow of information between different functions within the organisations, it does not solve the problem of recalling the information that best suits the individual.

2.5.2 CALS.

Continuous Acquisition and Life-Cycle Support (CALS) is an initiative by the American Department of Defence to improve weapon system acquisition and life-cycle support processes through the creation and application of digital product data and technical information. The CALS programme proposed that the exchange of technical information between Government, systems suppliers and their sub-contractors for the lifecycle of a system would be undertaken and controlled electronically.

The US Department of Commerce quickly recognised the commercial potential of the military project as a means of enhancing US competitiveness in world markets and actively promotes it to US industry. As many of the underlying concepts embodied in CALS are not specific to the defence sector, they can be applied as part of a business

process re-engineering strategy by all manufacturing companies that need to share and exchange information throughout the complete life-cycle of a product. The CALS concept is a framework of principles, tools and standards that enable the adoption of good practice in the sharing and exchanging of information. The standards to be used are published and emerging international standards, and specifications for the process of information exchange [DoDNavy]. Included in these are standards on how to mark-up the textual data, define data content and document structure using SGML (Standardised General Mark-up Language). In addition, these standards also define the general content, style, format, and user interaction features for interactive electronic technical manuals. SGML is an international standard that concentrates on specifying the structure of documents. One of the most popular application of this standard has been HTML (Hypertext Mark-up Language) used to structure information for use within the world-wide-web. STEP (Standard for the Exchange of Product data) is also an international standard that allows for the exchange of product data [Barker 98], thereby allowing different organisations with different systems to share the information.

Marland [Marland 98] suggest that there are serious doubts to the effectiveness of the current CALS standards when dealing with multimedia information and especially engineering drawings. However he also suggest that there is no difficulty in recognising open-hypermedia as one of the more advanced CALS Classes mentioned in the standards, as these do not have any detailed definitions attached to them. These different standards deal with how to structure the information at a low level. However, if this information is to be used effectively by humans who do not necessarily recall information in such a structured way, a method of linking these disparate systems is required.

Another use of the acronym is Commerce at Light Speed to emphasise the value of electronic commerce [UKCIC].

2.5.3 Supervisory Control and Data Acquisition (SCADA).

There are many ways to implement digital control of plant within a factory. Increasingly dedicated microprocessors are being used. However, with controllers being distributed around a factory, they are usually networked to a central computer. This central computer will not only enable the setting of the required parameters and setpoints of the control circuit, but will also allow the monitoring of the plant output. Such an arrangement is known as a SCADA systems [Dutton 97]. The central computer also communicates to

other computer system via the factory network [Lees 98]. Windows NT is now the de facto operating systems for running SCADA packages [Turnbull 98]. Monitoring of the plant data can also be viewed over the Internet [Reeve 98]. SCADA system can supply planners, maintainers, and managers with information on the state of the machine.

2.6 Summary.

The actual work practice of the industrial environment, for which the hypermedia application was developed, has been reviewed. The strengths and weakness of the current system and benefit of the hypermedia system have been identified.

At present the majority of information within an industrial environment is stored and distributed via non-electronic means (i.e. paper, microfiche). The common model used to control the issue, amendment and removal of documents is the ISO 9000 model. When introducing an industrial strength hypermedia application, there are many lessons to be learnt from the implementation of efficient and effective paper based information systems.

As the initial end users of the system will be the operators and maintenance technicians on the shopfloor, the emphasis has been on those information systems and controls that directly effect the maintenance function. There are various methods of implementing the maintenance of machinery in an industrial environment, the common feature being the management of the information. What is clear is that an effective maintenance strategy does rely on the ability to communicate the strategy effectively. This can only be achieved if the information system is clear, precise and easy to use. At present there are isolated small information systems, normally dedicated to an OEM, that aids the maintainers in their tasks. These systems will need to communicate with the other information management systems involved, if an effective and coherent system is to be implemented.

Chapter 3.

Design Process for Hypermedia Applications.

This chapter first reviews the major hypermedia design methodologies, with particular reference to the industrial hypermedia domain. Within the literature there are a number of hypermedia design methodologies, of which:

- The Hypermedia Design Model (HDM),
- The Relationship Management Methodology (RMM),
- The Object Orientated Hypermedia Design Model (OOHDM),

are considered to be the most significant.

The following sections review these methodologies, with a critique presented in section 3.4. Based on the review, a design methodology suitable for an industrial hypermedia application is presented. The design methodology developed reflects the language and constraints of the industrial environment.

For the design of a large-scale industrial hypermedia application the design team will, in all probability, include specialists from various departments, such as quality engineers, process engineers, procurement, finance, as well as computer science and Human Computer Interaction (HCI) specialists. Therefore, the language of the design methodology needs to be that of the industrial environment and the application developed needs to reflect the

many constraints of the industrial environment. A design methodology, in principle, is independent of any particular propriety software. However, with most industrial hypermedia applications, it can safely be assumed that some form of propriety software will be used, even if only to provide the basic hypermedia system. The general requirements for project management of a large-scale hypermedia application are similar to those of any large computer-based engineering project. There are copious amounts of literature on the subject of project management [Chapman 87, Thayer 90].

3.1 Hypermedia Design Model (HDM).

Garzotto et al, proposed a design model for hypertext [Garzotto 93] called the Hypertext Design Model (HDM). In their paper, they explain that the development of a hypertext system would benefit from a structured and systematic approach, especially in the case of large scale and complex applications. They describe HDM, as a first step towards defining general purpose models for 'authoring-in-the-large'. Authoring-in-the-large [Garzotto 95], allows the designers to obtain a description of the information element classes and the navigational structures of complex applications, independent of the implementation details. Some of the innovative features and terminology used in the HDM are:

- Entities which denote a physical or conceptual object of the domain. These consist of a hierarchy of components, which in turn consists of units. These units are the smallest chunks of information, commonly called nodes in hypertext.
- The notation of perspective which gives consistency in presenting the information of an entity type in different ways.
- The definition of different categories of links:
 - Structural links*: connect together components belonging to the same entity.
 - Perspective links*: connect together the different units that correspond to the same component.
 - Application links*: denote arbitrary, domain dependent relationships and connect together components and entities of the same or different types in arbitrary patterns set-up by the author.
- The ability to define a significant number of links from the conceptual-design level description (especially structural and perspective links that can be deduced from the structure or algorithmically derived).

HDM can be used in different roles:

- As a modelling device: to support producing high level specifications of existing or to-be-developed applications. It is particularly suited to applications where regularity, organisation, modularity and consistency are important.
- As an implementation device: it is the basis for designing tools that directly support application development.

HDM provides a framework for describing and analysing hypermedia applications. HDM is a design model of the hypermedia application and does not explicitly set out the methods required to create the application, therefore, it is not a design methodology [Lowe 97]

3.2 The Relationship Management Methodology (RMM).

This methodology was first proposed by Isakowitz et al [Isakowitz 95]. RMM is suited to hypermedia applications that have regular structures, those with classes of objects that have a definable relationship, and where there are multiple instances of objects between each class [Lowe 99].

This methodology is mainly concerned with a narrow data set of structured information, and is particularly suited to hypermedia applications where the classes have volatile data that requires regular updating i.e. product catalogues with regular structure. RMM is not appropriate for hypermedia applications that have regular structured and the data remain static for prolonged periods, or hypermedia applications that have volatile data with dynamic structures.

The RMM design methodology is shown in Figure 3-1, the core of the methodology is found in steps S1 to S3.

- S1: To represent the information domain of the hypermedia application via an Entity-Relationship Diagram. These entities and their relationship will form the basis of the hypermedia application, and will be implemented as nodes and links.
- S2: To determine how the information in the entity is presented to the user, and how the user may access it. This involves splitting the entity into useful slices and grouping them together. The organising of entities into slices is called the slice design phase and the links between the slices are called structural links. Structural links differ from

associative relationships in that structural links are between the same entity while associated links link to different entities. It is important to differentiate between the two for navigation.

- S3: This step involves designing the navigation paths. To enable updating of the information these are described in generic terms and not hard coded. This is achieved by referring to properties of the entities and their relationships.

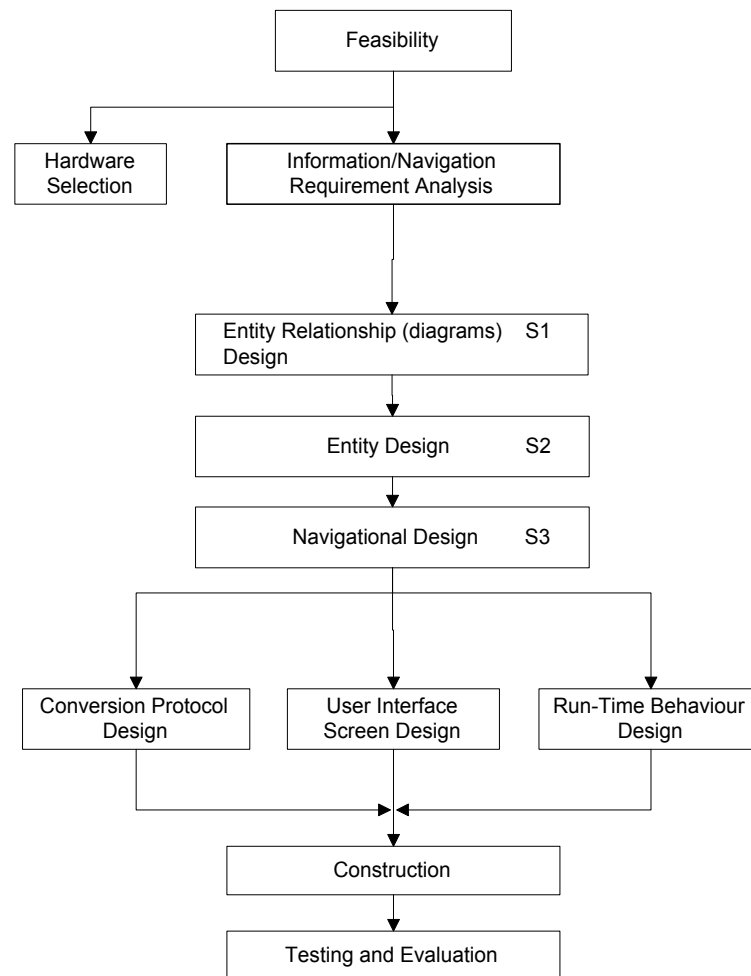


Figure 3-1 RMM Design Methodology [Isakowitz 95].

Due to the requirement for RMM to contain regular structured information in related classes, Lowe and Hall [Lowe 99] describe the system as being suitable for database applications, library loans or details of personnel in a company. In addition, while they point out that whilst RMM is good for information structure and process development, it has not been used for application requiring information re-use, application maintainability,

or cognitive management during the development phase. This combined with the restriction on the data and structure makes this methodology unsuitable for an industrial application.

3.3 The Object Oriented Hypermedia Design Model, (OOHDM)

This methodology was proposed by Schwabe et al. [Schwabe 95, Schwabe 96]. OOHDM builds a hypermedia application using an object-oriented framework. The design method uses a four-step process, each focusing on a particular design control. The four steps are:

- **Conceptual (or Domain) Analysis:** - The main aim of this step is to capture the domain semantics as naturally as possible. At this stage, little concern is made of the type of user or tasks. This results in a conceptual schema built out of subsystem classes and relationships.
- **Navigational Design:** - The Navigational Design reorganised the information of the conceptual analysis to take into account the intended users who are to perform certain tasks using the hypermedia application. This is achieved by defining a navigational model in terms of nodes, links (reflecting the relationships intended to be explored by the user) and access structures (indexes and guided tours). In addition, by taking account of how the user explores the information, the author of a hypermedia application is able to avoid the redundant information and prevent the user getting lost in hyperspace. By defining the navigational semantics in terms of nodes and links, a model movement in the navigational space can be made independently of the conceptual model.
- **Abstract Interface Design:** - In this stage, perceptible interface objects are defined in terms of interface classes. Interface behaviour is declared by specifying how to handle external and user generated events, and how communication takes place between navigational and interface objects. A clear separation between navigational and abstract interface design allows different interfaces for the same navigational model, giving a higher degree of independence.
- **Implementation:** In this final stage, the designer maps the navigational and interface models into a concrete object.

Separation of the design into clear steps allows the designer to focus on the important issues in each step. However, OOHDM does not cover the early aspects of the design process nor

does it address how the steps are co-ordinated [Lowe 99]. In addition, OOHDM requires that the industrial designers/authors not only need to learn the new hypermedia design methodology, but need to be conversant with Object-Oriented design methods and software. This is not practical in an industrial environment from which the author would be drawn.

3.4 Other Hypermedia Design Methodologies and Environments.

Nanard et al [Nanard 95] have set out the requirements for a design environment. They state that the range of hypermedia applications is so broad that no single formal design technique is relevant to all of them. They also say that any design environment should support:

- A fast experimental feedback loop, which facilitates the evaluation activity and process recursion, thereby improving design quality.
- Tools for generalisation and instantiating models, which enable designers to alternate among bottom-up and top-down approach, thus promoting both structure and updating activities.
- Easy and unconstrained cloning tools, which work at the instant level, thus supporting the generating material activity.
- The ability to easily build solutions that may be evaluated directly, regardless of the user's current stage within the formal design technique.
- Integrating light prototyping to evaluate design choices-at least the presentation and the navigation ones- at any stage of development.

They concluded by saying that formal design techniques improve consistency, but due to the human factors in the design, feedback is vital [Nanard 95].

Johnson [Johnson 87] also noted that regardless of a hypertext's size, the best quality-control tool is a skilled author and that it takes an author to distinguish actual errors from design choices.

Hutchings [Hutchings 93] has shown that the user task and the reason for using the hypermedia application are an influence on the way users interact with the hypermedia application. He suggests that it may be possible to make assumptions about the way in

which the application will be used in certain situations. Hence, designers can design tools specifically for that application

The design model suggested by Ginige and Lowe [Ginige 97] presents a clear distinction between the design processes and the authoring processes. Ginige and Lowe collected the design processes into a group that they call the creative process. This is a multi-discipline stage that will involve application specialists, computer scientists, graphic designers, HCI specialists; etc. This overcomes some of the limitations of the RMM by including the specification in the process (see Figure 3-2). They recommend that the specification include the following inputs:

- Technical issues;
- Content Outline;
- Cognitive issues;
- Non Technical Issues.

And the output from the design stage should address the following issues:

- Information Structure;
- Information Access Method;
- Look and Feel;
- Guidelines for Content Development.

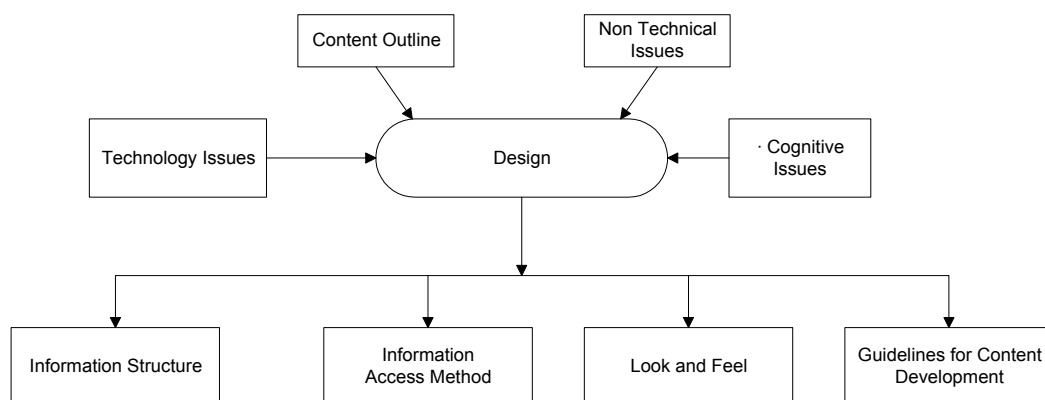


Figure 3-2. A hypermedia design process (Ginige and Lowe)

As reported, Balasubramanian et al rejected the RMM, HDM and OOHDM methodologies and models when designing a large-scale web site for a financial-management company [Balasubramanian 97]. The reason given was that they all require the application domain to

be abstracted in the forms of entities or classes and relationships. Hence, Balasubramanian's model is not applicable to this application as it was specifically designed for the WWW domain, with the WWW limited link functionality, set document formats, and limited user interface. However, Carr et al [Carr 94] have demonstrated that the link functionality on the WWW can be extended. Using such a system Hughes [Hughes 99] has develop a dynamically generated web site, in which word processed documents are converted from their original format and automatically linked.

3.5 Comment On Previously Published Design Methodologies

A method of quantifying the effectiveness of the methodologies against some criteria is required. To remove bias, this set of criteria for quantifying the effectiveness of a hypermedia methodology should be one that is already established and recognised by the hypertext community. Christodoulou et al [Christodoulou 98] have presented such a framework for evaluating hypermedia application development and management systems (HADMS). The evaluation framework consisted of a set of criteria, against which the hypermedia methodologies and environments can be assessed. They suggested that a designer would select which criteria are important for their application. The designer then applies a scoring system to select an appropriate methodology or system that best meets the chosen criteria.

The criteria Christodoulou et al. used are based on the Object Orientated Design Methodology (OOHDM). Christodoulou et al. justified this by saying that although the different methodologies followed different steps, on careful examination most of the methodologies are based on the four basic steps used in OOHDM. These steps are Conceptual Data Model Design, Abstract Navigational Model Design, User-Interface & Run-time Behaviour Design and Implementation.

Christodoulou et al. then set up three example applications and rated a number of hypermedia methodologies and implementation environments according to their ability to fulfil the requirements of the hypermedia application. The methodology that did well overall was the OOHDM, but it had no hypermedia environment in which to produce applications. Hence, they concluded by saying:

'It was observed that no HADMS (methodology and the corresponding environment) is efficiently covering the evaluation criteria. Also, there is no existing full-featured HADMS that one can use to develop different kinds of applications with different requirements.'

The first stage, in quantifying the effectiveness of the methodologies, was to establish which criteria were applicable to an industrial application. These were established from the requirements specification for the FIRM project [Crowder 96a]. The criteria for an industrial application were then rated, as: - Not Required; Desired; Highly Recommend; or Required. The evaluation criteria were then converted to scores, that is: Not Required assigned the value 0; Desired value 1; Highly Recommend value 2; or Required value 3. The criteria are listed in Table 3-1 and Table 3-2. A full explanation is given in Appendix C.

	Criteria	Requirements
A	Common	
A1.	Structural constraints.	Required
A2.	Design evolution	Highly Recommended
A3.	Reusing and tailoring.	Required
B.	Conceptual Data Model Design	
B1.	Basic hypermedia support.	Required
B2.	Multimedia support.	Required
C.	Abstract Navigational Model Design	
C1.	Semantically.	Desired
C2.	Composites.	Highly Recommended
C3.	Semantically typed links.	Required
C4.	Link attributes.	Required
C5.	Bi-directional links.	Desired
C6.	Anchors embedded in node content:	Required
C7.	Internal link update mechanisms,	Required
C8.	Automatic creation of links among nodes,	Required
C9.	Global and local views,	Required
C10.	Node and link participation in different views.	Required
C11.	Access structures.	Required
C 12.	Personalization features (user profiling).	Highly Recommended
D.	User-Interface & Run-time Behaviour Design.	
D1.	How interface objects map to navigational objects.	Not Required
D2.	Specification of run-time behaviour to interface objects.	Required
D3.	Synchronisation of interface objects,	Desired
D4.	User-defined instantiation.	Highly Recommended
E.	Implementation issues	
E1.	Dynamic content.	Not Required
E2.	External storage systems. .	Required
E3.	Simplicity.	Required

Table 3-1 Methodology Criteria Requirement for an industrial application

	Criteria	Requirements
F.	General	
F1.	Client/server distribution.	Not Required
F2.	External tools.	Required
F3.	Extensibility	Required
F4.	Importing.	Required
F5.	Content-based information retrieval mechanisms.	Required
F6.	Structure-based information retrieval mechanisms.	Desired
F7.	Supporting utilities.	Not Required
F8.	Quality testing.	Not Required
G	Collaborative	
G1.	Simultaneous multi-user access,	Not Required
G2.	Access control.	Not Required
G3.	Member activity tracking.	Not Required
G4.	Notification controls.	Desired
G5.	Versioning at the level of individual entities	Required
G6.	Annotations (private, workgroup or public).	Desired
G7.	Interactive collaboration.	Not Required
H.	User Interface (UI).	
H1.	UI of the design and implementation environment	Required
H2.	UI of the authoring environment,	Required
H3.	Intelligent user assistance,	Required

Table 3-2 Environment Criteria Requirement for an industrial application.

The next step is to evaluate the design and authoring methodologies. The methodologies and environment were rated as: - not supported assigned the value 0; poor support value 1; acceptable support value 2; or fully supported value 3. The score for the other models were derived from the ratings given by Christodoulou et al. The method used by Christodoulou et al limits the score allocated to the criteria, for each HADMS can not have a value higher than the criteria set for the application. For example, if the criteria for the application are rated as a 1 (Desired), even if the system is fully implemented (normally scores a 3) it is reduced to 1.

The score for each individual HADMS was calculated by summing the scores for each of the applicable criteria. These scores are then normalised by dividing each of the system scores by the score from the industrial application criteria. The results are summarised in Table 3-3. While, a description of OOHDM and RMM has been described in this Chapter, a very brief description of the other systems is given in Appendix C. Based on the score in Table 3-3 it can be seen that over all the ability of any existing HADMS to satisfy the requirements of an industrial application is limited.

	Industrial Requirements	OOHDM	RMM	HSDL	HSM	Strudel	Story	FP
Methodology (criteria A-E)	1	<i>0.768</i>	<i>0.429</i>	<i>0.554</i>	<i>0.625</i>	<i>0.393</i>	<i>0.482</i>	<i>0.375</i>
Environment (criteria F-H)	1	-	<i>0.259</i>	<i>0.444</i>	<i>0.370</i>	-	<i>0.926</i>	<i>0.555</i>
Overall	1	<i>0.518</i>	<i>0.373</i>	<i>0.518</i>	<i>0.542</i>	<i>0.265</i>	<i>0.626</i>	<i>0.434</i>

The scores in italics are derived from the original evaluation by Christodoulou [Christodoulou 98].

Table 3-3 Normalised results of the evaluation.

In addition, the published design methodologies described above all assume that hypermedia application authors have complete control over the content of the information space. In an industrial environment, there already exists an established information space, which will, in all probability, have structure, content and access methods. Therefore, these existing systems need to be encompassed into the design of any industrial hypermedia application. In addition, the above models are general models and methodologies often citing examples far removed from an industrial environment, for example academia teaching, catalogues, and museums. No one model covers all the requirements for developing an industrial hypermedia application. That is, they do not: -

- Cover the early aspects of the design process, nor do they address how the steps are co-ordinated in order to create the application.
- Take into account the implementation of the design methodology by personnel from within the industrial environment.
- Address the issues of information re-use, application maintainability, or cognitive management during the development phase, within any one model or methodology.

The majority of the industrial hypermedia applications that have been published in literature, on close examination, used embedded link technology [Greenough 98, Garzotto 91]. Very few publications describing the method used to design the industrial hypermedia application and those that did, did not use open hypermedia.

Beyond the limitations discussed above, there are four main areas specific to large-scale industrial hypermedia design, in which the size and complexities of the task allow the potential for errors to occur, these are:

- The increased cognitive burden to the author.
- The maintainability of the system. There is now a requirement to maintain the links and ensure that they are still valid if a document is moved or deleted.
- The reuse of information must take into account the perspective implied by the links.
- The scalability of the system must allow documents to be added and deleted in a coherent way.

In light of the limitation of the current methodologies, this justifies the decision to develop a new design methodology, that will satisfy the requirements of the industrial environment. This new model must take into account the structures and constraints that exist in an industrial environment, and the background of the people who will have to design and implement any hypermedia system. The design methodology needs to be flexible enough to accommodate the current and future philosophies within manufacturing industry.

3.6 Design Methodology for an Industrial Environment.

The design of an industrial hypermedia application is an iterative process, which is described below. The design process is shown in Figure 3-3.

3.6.1 Specification

As with any engineering project, one of the first tasks is to establish the project requirements and develop the specification. The specification for a large-scale industrial hypermedia application may well consist of several stages. An initial requirement specification is produced which will describe in broad terms what is expected of the industrial hypermedia application. The initial requirements may be followed by a feasibility study examining available software systems, current applications, literature review, cost benefits and possibly a mock-up of the system. This will be followed by a detailed requirements specification, against which the delivered system can be measured.

The use of techniques such as Quality Function Deployment (QFD) can serve as an aid to translating the general description of the customer requirements into tangible design requirements [Down 94].

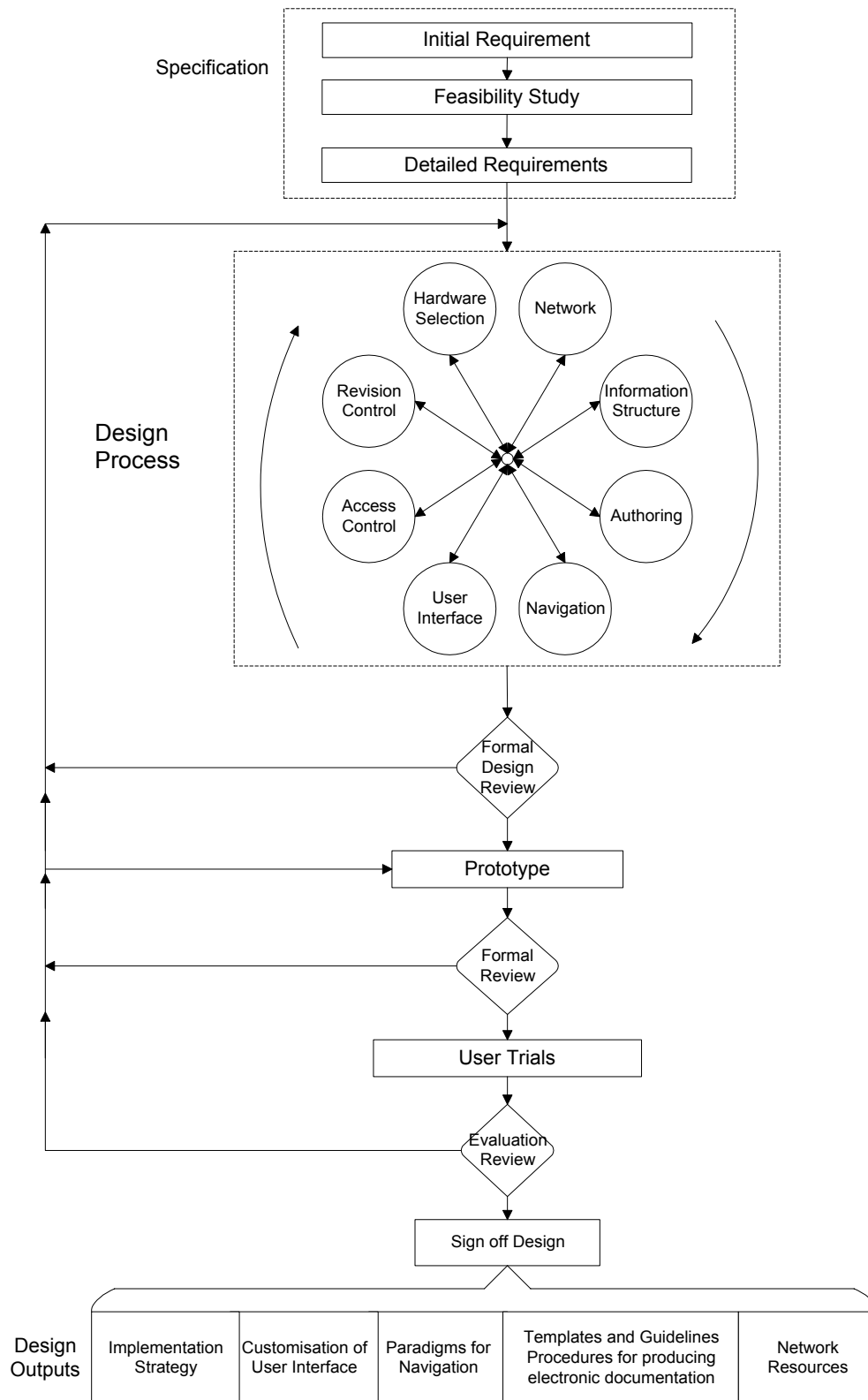


Figure 3-3 The proposed design methodology for an industrial strength hypermedia application.

3.6.2 The Design Process.

The design process by its very nature is an iterative process. An overview of the essential elements in this iterative process is described below.

3.6.2.1 Information Structure.

The industrial environment will generally already have a large established information space. This naturally creates different views of the information depending on who is accessing the information, which task they are undertaking, and what piece (if any) of equipment is being used or worked on. Therefore, the information is not represented by a single structure and by using the principle of linking, via hypermedia, any number of information structures can be obtained. Therefore, in the case study's information space shown in Figure 2-5, there are few lines representing fixed relationships between the islands of information.

However, by using the 'natural' hierarchies that exist within the organisation, several possible structures to the information can be overlaid onto the information space. These 'natural' hierarchies can then be used to aid authoring and give an initial structure to the hypermedia application, as well as identifying and allocating responsibility for maintaining the different areas within the information space. In practice, the information will be 'owned' by a particular department or job function. For example, within Pirelli, Technical Instructions are controlled and written by the engineering department, for use in many other departments.

In addition, examining the structure of the information space can form a basis for a global information audit. The designers will be able to identify the types and formats of information systems used, the type and approximate number of documents, and the processes required to integrate the information into an industrial hypermedia application.

3.6.2.2 Authoring.

Authoring a hypermedia application is the name given to the process of producing the links within the information space and is an integral part of the design methodology. The design output associated with the authoring process will be templates, procedure and guidelines on

producing electronic documentation that can be easily integrated into an industrial hypermedia system and, if appropriate, the programmes for automatic link generation.

In addition to the constraints of using the existing and established information space, with its structure, content and access methods, the designers are further constrained, in that the personnel used to implement the authoring methodology are unlikely to be IT specialists. That is, the implementation for most of the structural linking will be performed by clerical assistants and with other specialists (procurement managers, engineers, process owners, quality etc) used to carry out the pedagogical and conceptual links.

The authoring process is a complex procedure yet also constrained by cost and time factors. It is, however, still one of the largest costs of producing a hypermedia application. Hence, a detailed authoring methodology is examined in chapter 4.

3.6.2.3 Navigation Considerations.

Navigation can be viewed as a combination of hypermedia linking, information retrieval and document management. While navigation, user interface, and linking mechanism design are closely associated, they are initially treated as separate issues. This ensures that the designers do not limit their options too soon. It is important that the designer examines ways of navigating the information space that are neither dependent on, nor limited by, the user interface or linking mechanism, at least in the initial iteration. This allows the designer to explore and use the natural structures that exist, the context in which the application is to be used, the specific user requirements, and paradigms for the use with electronic information. The output will be a description of the paradigms for navigation to be used. This will help design the navigation tools required and help define the content of the training courses for the users.

3.6.2.4 The User Interface.

The user interface is the means by which the user will initially judge the application and therefore is a key element in influencing the success of the hypermedia application. It is via the user interface that the designers provide the tools by which the user accesses and navigates the information space, maintains the system and authors further hypermedia application.

Different user groups will have different abilities and require different functionality from the system. Therefore, while a common look and feel should be given to the user interface, providing exactly the same interface for everyone could cause problems.

The designers can be constrained by the user interfaces provided by the software.

However, a degree of customisation is generally possible. Page et al [Page 96] recommend that expert users be allowed to customise the interfaces, to improve efficiency. In this design methodology, the settings for the customised interfaces will be an output of the design stage and will be based on the results of user trials.

Navigation and user interfaces, for an industrial hypermedia application, are considered as part of the subject of evaluating Human Computer Interaction, presented in Chapter 7.

3.6.2.5 Access method.

This stage of the design examines how the user is to access the information space. This is initially treated separately although it is closely related to the navigation paradigm. The hypermedia application should use a series of permissions, with the user being shown only those options allowed by their particular access permissions. In practice, this could mean either different menus and/or linkbases controlling access to the information space menu, thereby creating different paths through the same documents. For example, on the process line, the operator may not be shown any links to the maintenance information, while the maintenance personnel may be able to follow both the operators and maintainers links.

3.6.2.6 Revision Control.

The method of documentation revision control will vary from company to company.

Therefore, the design methodology does not aim to replace the company's documentation management system, but to operate with it. However, the links themselves are sources of information as much as a line of text or an object in a drawing. Hence, during the revision control process, it is necessary for the hypermedia system to log the changes made to the application linkbases. In order that this does not become an administrative nightmare, the process is simplified to only record links that have changed. The subject of link management is discussed in more detail in chapter 4.

3.6.2.7 Hardware Selection.

Irrespective of how well the information is presented or intuitive to use, it can rapidly be undermined by the frustration felt by the user at not being able to access the information quickly. The speed of access to the information is largely governed by the choice of computer and network. The areas to be considered during the design process are:

- The environment in which the equipment is to be used. The factory floor is a hostile environment for any piece of office equipment, in particular computer-interfaces, hence novel interfaces may be required.
- The delivery of information to the point of use. To be of use the delivery computer must be capable of operating anywhere within the factory environment. It would be of little benefit if the shop-floor users had to walk over to a workbench to access the information.
- How the information is to be stored and accessed, i.e. should the information be accessed locally or remotely? If accessed remotely, should local area or wireless networks be used? Ideally, the original documentation should remain on its original server, removing the administrative burden of maintaining ‘controlled copies’ of CD-ROMs.

The answers to these questions will affect the hardware selection. The design output, from this section of the design, will be the defining of the network and computing resources requirement for the introduction of the application across the whole organisation.

3.6.3 Design Reviews.

The requirements and procedures for design reviews, within industry, are well established. A generally accepted model is the one described in BS EN ISO 9001 [BSI 94]. In addition, there is a guide to implementation of BS EN ISO 9001 specifically for software [BSI 97]. From the iterative design process represented in Figure 3-3, it is possible to enter an infinite loop, if problems are encountered. In practice, this rarely happens due to good project management and the constraints of time and cost.

3.6.4 The Prototype Application.

The prototype application must be representative of the final system, and be exposed to representative from the different user groups. A practical approach is to use the information space associated with a process line, or part of a process line depending on the size, as this approach naturally includes personnel from across the organisation. Expert evaluation of the user interface should take place during the testing of the pilot application [Wills 97], thereby, reducing the number of major usability problems encountered in the user trials. In addition, the training programs and test scenarios can be developed at this stage in preparation for the user trials.

3.6.5 User trials.

This stage should be highly interactive between the users, evaluators and the design team. The evaluation methods used will vary depending on the application domain (size and requirements). However, in an industrial environment the evaluation can, to some extent, be divided into three main areas: -

- Training the users. It is good practice to profile the users prior to training, as this is useful for assessing the effectiveness of the training program and system at a later date.
- Conduction system evaluations. Here the users perform pre-set scenarios with comments on the usability and suggestions for improvement being fed back to the design team.
- Allow the user freedom to explore the system. The users are encouraged to use the system as much, or as little, as they require for their daily work.

3.6.6 Design Outputs

The design outputs allow the full implementation of the industrial strength open hypermedia application within the organisation. This includes lessons learnt from the implementation and evaluation of the prototype, and from the training of users and authors of the application. These will be summaries in the implementation strategy document. The implementation strategy draws together all the different aspect of the design process. In addition, it will detail who is responsible for what and by when, the resources required, and the processes to be followed. Therefore, the implementation strategy will be unique for each organisation.

- The implementation strategy.
- User interface specification.
- Navigation paradigms.
- Template and guidelines for producing electronic documentation.
- Network resources required.

3.7 Summary.

The general design solutions described assume that the authors of the hypermedia application have control over the form, size and/or the content of the information space. In an industrial environment, there already exists an established information space, often consisting of several different information systems, with existing structure, content and access methods. Therefore, these must be encompassed into the design of any industrial hypermedia application. The current models fail to achieve this and often cite examples far removed from an industrial environment. The industrial design methodology proposed removes much of the generality of the current models and focuses on the requirements and considerations for designing large-scale industrial hypermedia applications.

In summary, a design methodology that takes into account the structures and constraints that exist in an industrial environment and the background of the people who will have to design and implement the system has been proposed.

Chapter 4.

Hypermedia Authoring.

The cognitive processes of the human mind tend to organise and recall information through association. Hypermedia allows people to partially mimic this process, by using hyperlinks to make associations within information, corresponding with the way in which they naturally access and manipulate information.

This chapter presents and critically examines the general authoring methodologies presented in the literature and proposes an authoring methodology suitable for large-scale hypermedia applications for the industrial environment.

Ginige et al [Ginige 95] state that similar issues arise in developing hypermedia applications, as in paper based systems. These are:

- How to structure the information, which will inherently depend on the underlying structure.
- The scale and intended use of the hypermedia application will determine the methodology used.
- The information structure is determined by: the material that will be included; the underlying structure of the information and any subsets that are to be supported; and the navigation accessing method (table of contents, index, full text, and key word search).

They suggest that creating hypermedia applications can be divided into two main areas:

- Authoring: The processes of working and storing the information in a fashion appropriate to the intended use of the information.
- Publishing: The process of presenting the information to the user, including issues such as task and feel, screen layout and usability.

They also state three common authoring approaches: program language, screen-based, and information-based. The one most applicable to this research is the information-based approach where the content is obtained from existing information. The information is collected, structured and stored on a database. The author then links related concepts and determines how the information should be presented on the screen. Keeping the original structure of the information allows the viewpoint of the original author to be retained. This is well suited to the development of large hypermedia information systems that require a well-defined process.

Structuring the information involves [Ginige 95]:

- Identifying key concepts that best describe the information, these are of use later when searching for specific information.
- Breaking down the information into nodes. Each node should contain only a single theme. Nodes typically contain information that would lose all usefulness if broken down further.

Perlman [Perlman 89] also found that when structuring or restructuring information, it was useful to consider the goals of the users, concluding that different tasks may be better supported by different chunking and structuring. In addition, he noted that experienced users avoided getting lost in hyperspace by using bookmarks. Hutchings [Hutchings 93] suggests that along with navigational aids, some form of guided tour would further enhance the ability of naive users to familiarise themselves with the application.

The greatest challenge when linking a large industrial hypermedia application, is the need to mentally manage all the existing nodes within the information space. The mental management of a large number of links will, in all probability, produce a cognitive overload to the author. This typically becomes a problem when the information space typically grows above 100 nodes. On smaller hypermedia applications, this problem can be

overcome by using link maps, which show (sometimes pictorially) the source and destination of the links.

Information structures can be broken down into three main groups.

- Linear: The nodes are linked in a linear sequence so that the user can only progress in the sequence set by the author. This is useful in retaining the sequential order of the original paper document. Binding several nodes together in a 'guided tour' or hypertrail, commonly serve as instructional aids, or procedural instructions (used in training manuals) where the user must first complete a topic before progressing to the next step.
- Hierarchical: Can retain the original structure of the information in a hypermedia database. Also allows a system table of contents to be used as a point to start reading from, or as an access point to allow the user to jump to information elsewhere within the system.
- Network: This structure consists of associative links. These are semantic or pragmatic in nature and truly non-sequential. They bind common or related concepts together within the information space. The ability to browse in a felicitous manner is a major advantage of hypermedia systems.

It has been argued that authoring really is a production process in which conventional authoring, making the links is but a small part [Ginige 97]. The rationale behind the argument is that, authoring involves gathering and digitising the information, dissecting large documents, generating the links, manually or otherwise, within the information space and storing the information, see Figure 4-1. The process shown describes the one-off process required to produce a hypermedia application for many of the reported application. This does not accurately represent the process required for an industrial hypermedia application, as the information content cannot generally be changed or edited without going through a change request procedure. In addition, some of the information will already be in propriety electronic information systems, with information needing to be added or removed with relative ease. Ideally, this process of adding and removing information should be mechanised.

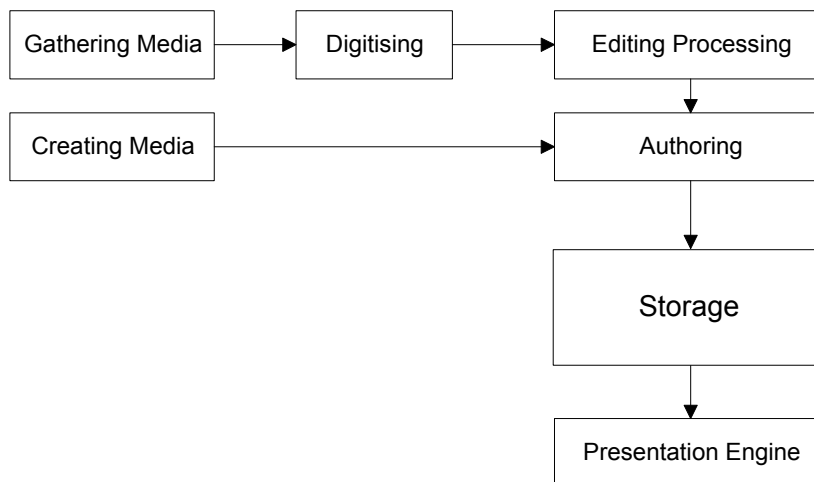


Figure 4-1. The authoring of a hypermedia application has been described as a production process.

4.1.1 Automatic Link Generation.

Manually linking of information can be a tedious and monotonous process, and as such can be very error prone. This becomes more significant as the system gets larger and the cognitive burden for the author increases. Hence, automatic generation of links is an important area of research [Bulford 96, Cleary 96]. Allen [Allen 96] has suggested that pattern matching can be used to find the structural links of a document. Structural links represent the layout or structure of a document. Carr [Carr 94] refers to the structure of technical documents as having a superstructure. Carr was able to use the structure and a mark-up language to produce embedded links into a document. That is, the author had to mark-up the document in one application prior to running the process that created the links in another application package.

4.1.2 Information Reuse.

Information in an industrial environment is only rarely used in one place. For example, a process line will often consist of several major pieces of equipment that are integrated together. These major pieces of equipment will often consist of sub-systems used elsewhere on the process line or within the factory. Similarly, in other parts of the organisation, procedures, reports, etc are used by more than one department. Information therefore can be reused. The industrial application of reuse is more fully explored in section 4.2.

Garzotto et al [Garzotto 96] have set out a classification for node reuse. While their work is mainly on the classification of reuse of nodes, they do give a number of areas that need to be considered when reusing information:

- Reuse requires careful implementation and design. Hence, reuse is not free.
- To avoid ambiguities a schema is required at the start of the design process to describe the choice of reuse.
- As a general rule, unnecessary changes of presentation should be avoided.
- When a node is crafted, reference to elements outside the node itself should be avoided, as these are liable to create problems when the node is placed into a different context.

The classification system used by Garzotto et al is specific to the application used. While the specific application used to demonstrate their classification system is a good hypermedia application, it is different to the industrial application in both the type and breadth of information and the type of users.

Hardman [Hardman 89] also found that reusing or duplicating objects such as 'show me where' buttons had also caused problems.

4.1.3 *Link Integrity.*

Many people have felt the frustration at following a link in a World-Wide-Web document that ends in an error message, as the destination no longer exists. This may happen for a variety of reasons, the most common being that the document has been deleted or moved, and results in a 'dangling link'. This is very common in distributed systems and is overcome by insisting that the server system and human administration inform any link service that a document has been moved or deleted [Risk 97]. However, links can still become invalid when a document is edited.

Davis [Davis 95] has shown how some of the link integrity issues may be solved in Microcosm. He suggests that within the description of the link, two new tags should be added for the source and destination document. The tags recorded the operating system's date and time stamp when the link was created. At the end of the filter chain resides a 'checker' to see if the links for the document are older than the document date. If this is the case, that is the document has changed, the system will try to ensure that the links are still valid and inform the user that the document has changed and that the links may not be

valid. Davis refers to the problem of invalid links as the 'editing problem'. He suggested that the editing problem is more severe than the problem of a dangling link, as given a close file or virtual file system, it is possible to prevent dangling links. He also suggested the simplest way to deal with concurrency problems is not to allow them to happen, that is documents and linkbases are read only. He then describes a crude locking and notification procedure to ensure that only one author edits a document at a time. Davis suggests that it is necessary to impose some conditions on the use of the system if link integrity is to be assured.

4.2 Authoring Methodology for an Industrial Environment.

While the above general authoring methodologies, address some of the requirements for authoring an industrial application, the size and complexity of an industrial application aggravate some of the problems found in general hypermedia authoring. Such as:

- Time and cost required to author.
- Cognitive burden to the author.
- Maintainability of the information, i.e. additional document control standards.
- Information reuse. Reuse simplifies the controlled growth of the system.
- Existing information systems also need to be interfaced.

Hence, an authoring methodology is required that takes into account these considerations. The authoring methodology for the industrial environment is a direct consequence of the outputs of the design methodology outputs discussed in Chapter 3 and will include aspects of the best practice of paper-based documentation management systems and hypermedia authoring.

New hypermedia applications are written as a collection of nodes and linked together to give some form of structure. Linking within an industrial hypermedia application should ensure that:

- All relevant procedures, standards, fault trees, drawings, tool list, safety instructions etc, are included.
- Where possible, links should be grouped into a logical and cognitive structure.
- The procedural information is linked together to give a pedagogical structure.

A summary of the complete authoring methodology for an industrial environment is shown in Figure 4-2.

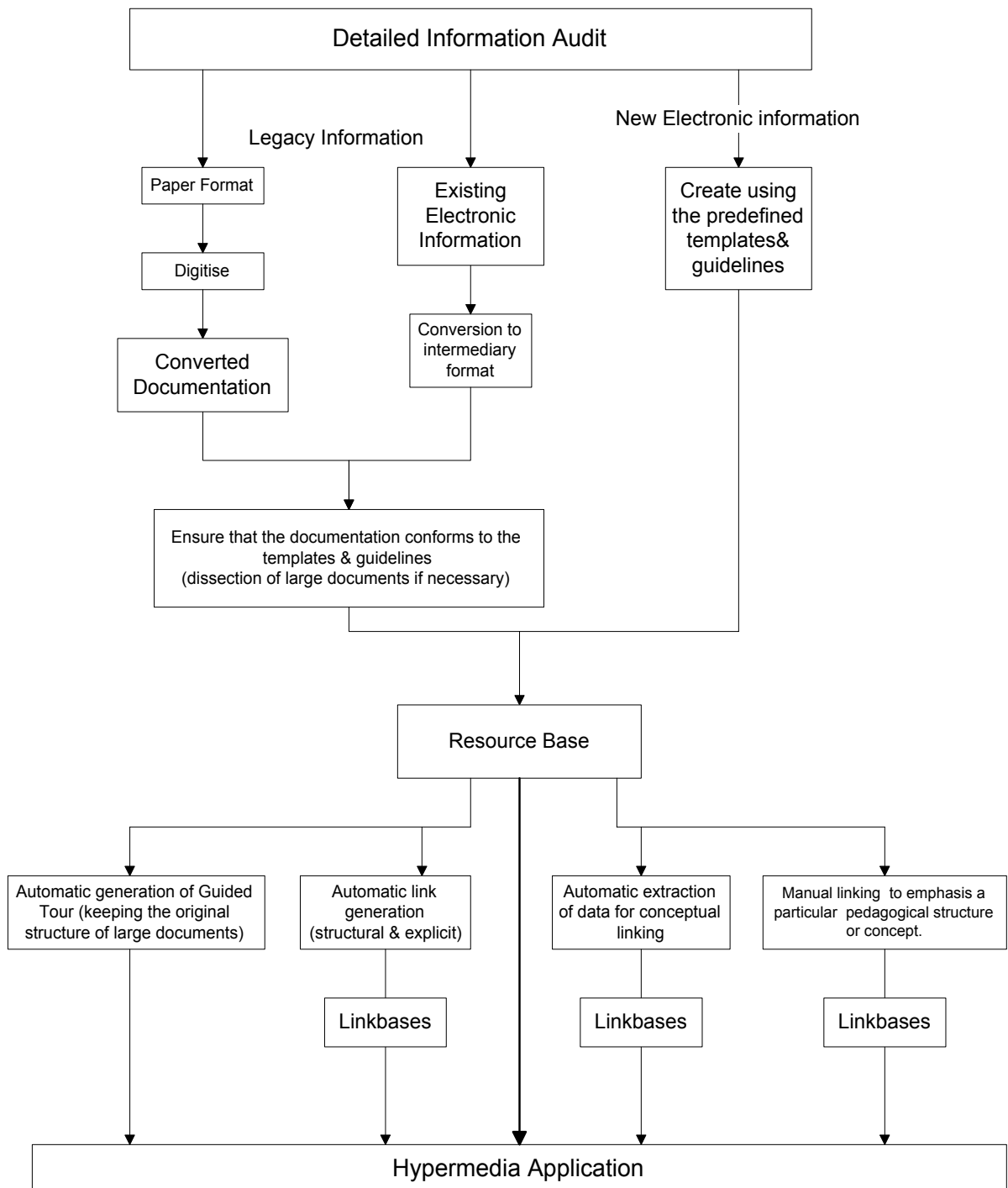


Figure 4-2 The Authoring methodology for an industrial hypermedia application.

When authoring, a paradox exists. The documents (or nodes) need to be as short as possible while maintaining their meaning. This will aid updating and revision control. While at the same time, the documents need to be long enough so that the system is not continually accessing the storage medium. This is especially important if the storage medium is not

physically part of the delivery system. Therefore, existing 'large' text documents are to be 'dissected' into smaller nodes. The nodes are linked together, so that the original structure is still available. As the documentation is dissected into nodes, meaningful labels/titles must be used for each dissection. Hence, the user will be able to navigate a technical manual, for example, by using a contents page, or step through the nodes as if they were pages, or jump straight to a node from another document.

The industrial authoring process is described in more detail below.

4.2.1 Detailed Information Audit.

The design process will have produced a global information audit. However, a detailed information audit of the specific working environment is vital, in order to identify exactly what information is to be included in the application. This can be conducted at the same time as the contextual review. Once the information audit is complete, an estimate of the effort to produce the application can be made. The information audit should identify:

- Existing information in paper format that will need converting. The whereabouts of the master or original documents, and the level to which it is to be converted, i.e. whether the documents need converting to vector format or remain in a raster format. Similarly to what level are the forms to be converted i.e. simple templates or database type forms?
- Existing electronic systems and the level of integration required. This is to identify the required effort to enable the different systems to communicate with each other.
- Existing electronic information and the level of conversion. Within each electronic system, the information will have been written for display in a certain format.

Therefore, if the hypermedia is to have a consistent look and feel, the authors will need to identify which pieces of information require modification, to conform to the procedure/guidelines for producing new documents. The type of changes needed will be dissecting very long and commonly used documents into useful nodes, left justifying text, removing large amounts of 'white space', setting style formatting in text documents, using blocks in drawings etc.

- Existing information that is not currently in documentation control. This includes information that is kept in logbooks or other 'useful' information as reminders of good work practice.

- Additional information not yet included in the documented information space. This would include menus for navigation, information that could now be included such as video, sound, photographs, background or educational material, etc.

4.2.2 Modular-Hypermedia Applications and Information Reuse

The Pirelli process line consists of several major pieces of equipment that are integrated. Figure 2.1, this layout facilitated separating the line into self-contained zones. For example, the Supertension line at Pirelli contains two caterpullers, each incorporates a drive unit. The drive unit consists of a motor, gearbox, cabinet, and a dc drive. In addition, the drive controller is also used on other equipment within the line and on other process lines within the factory. The information for these individual components can be viewed as objects of information, Figure 4-3 shows the different components of the caterpuller.

The information relating to the equipment on a process line has the advantage that it essentially can be associated with a physical object and not just a concept. Hence, reuse can be considered a free, as it is a much lower cost, in an industrial hypermedia environment, for objects at the same revision level.

The information for each piece of equipment has been authored separately, as a complete hypermedia application and comprises:

- Microcosm specific: Filters, Linkbases, and Computed Links.
- Application Specific: Engineering Data, Documents, Pictures, Videos, Procedure, Safety instructions etc.

Although the size of these applications are small compared to the eventual size of a factory wide hypermedia application they are however a complete application, and hence are termed Modular Hypermedia Applications (MHAs). MHAs will save time and therefore cost in not having to re-author the same information for units at the same revision level and modification state. MHAs also enable portability and modularization of components and subsystems on the process line. Hence, a MHA may itself contain several other separately authored MHAs.

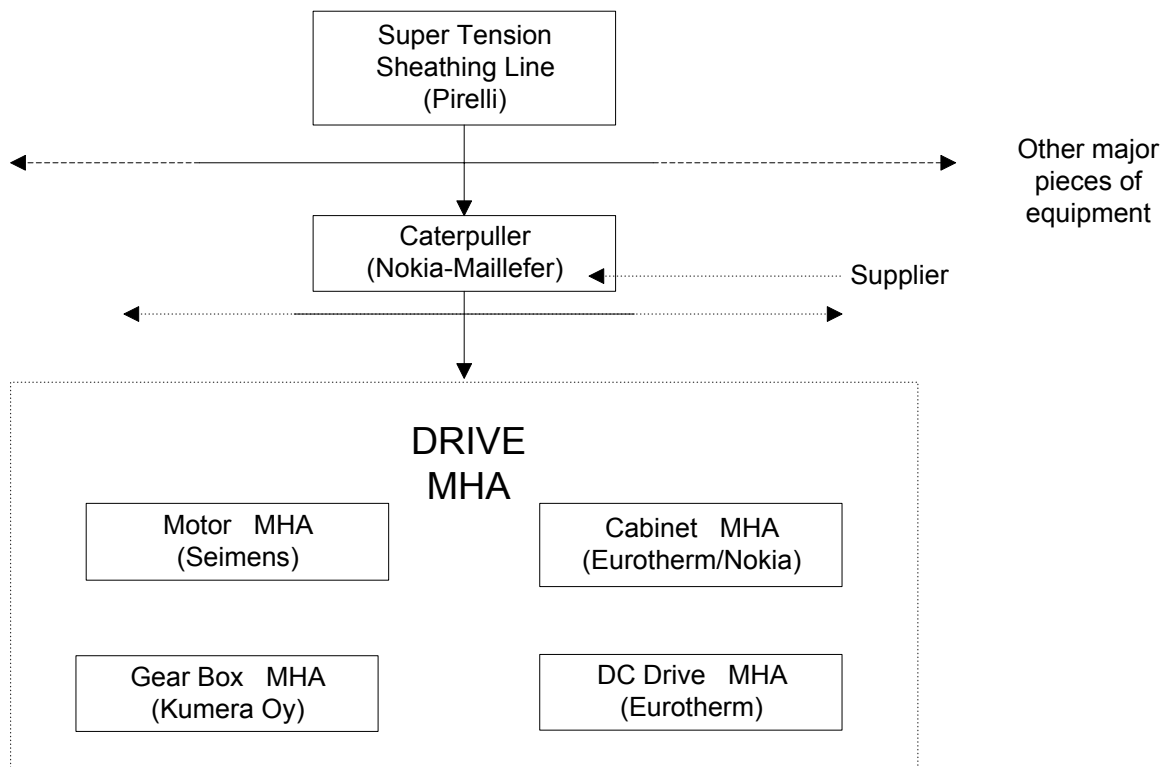


Figure 4-3 Assembly of a MHA using pre-authored components from different manufacturers.

A similar process is then used to include all the other information within the factory as a whole, building the information space out of MHAs. These applications can be created ‘off-line’, building in to a library of pre-authored MHAs. It is envisaged that the information relating to equipment supplied by OEMs will be electronic hypermedia manuals, pre-linked and ready to integrate into the hypermedia application.

If a slice through the information space is taken, the structure will appear hierarchical. However, in practice the growth of the information space will be dendritic in nature. By creating the larger applications out of MHA, the author is able to use current tools and techniques normally limited to smaller hypermedia applications, such as link maps. Also the smaller application becomes more manageable and reduces the cognitive burden to the author.

The hierarchical structure shown in Figure 4-4 can also be represented in Microcosm using logical types, similar to folders in File Manager or Windows Explorer. However, Microcosm does not store the files in these logical types, but only supplies a pointer to their

location in the file management system. Hence, the same file can be referred to many times in different logical types, and yet only one copy will exist.

Each concept or pedagogical structure is represented by a different group of links, each group being held in a separate linkbase. In addition, links referring to information external to the MHA are kept separate from those linking information only internal to the MHA. The use of separate linkbases increases the maintainability of the MHA. In addition, when reusing information the separation of internal and external links enables the danger pointed out by Garzotto et al [Garzotto 96] to be easily identified.

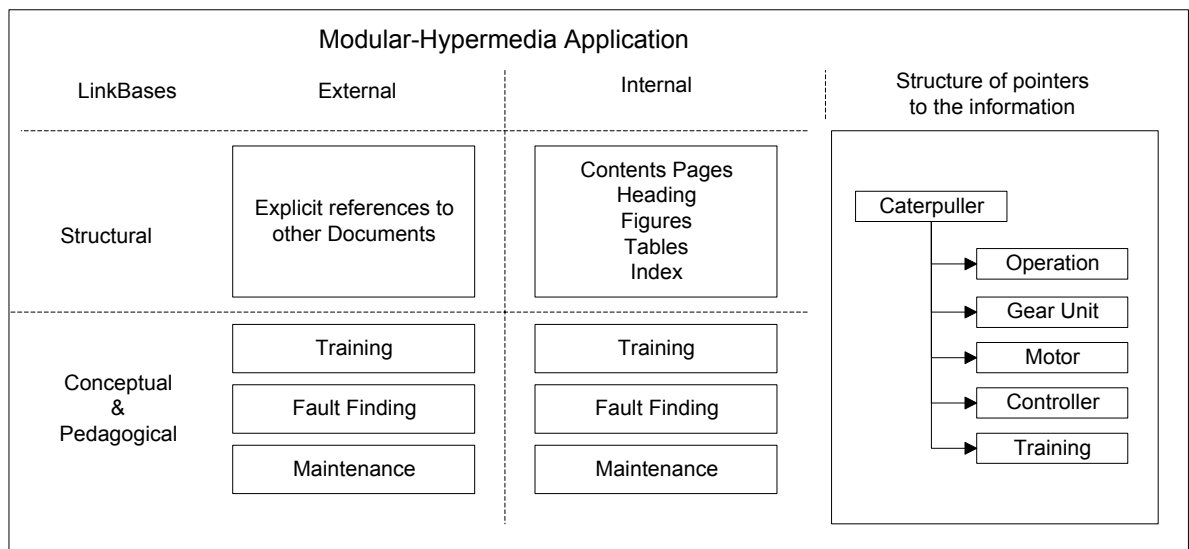


Figure 4-4 An example of how different linkbases are used to aid maintainability, resuability and authorability of a MHA

This method of hierarchical authoring enables ease of navigation, as the links will apply only to the hypermedia application for which it is originally built and any other application the author imports them into. For example, a machine manual will have a section on changing the bearings. This is then imported as part of a MHA for the whole line. However, when maintainers are working on a particular machine and need to locate the information relating to changing the bearings for that machine, they do not want to know about changing the bearings on any other machine. Yet, if the users are looking at the line level and queries the system on changing bearings they may want the information on changing the bearing on all the pieces of equipment.

4.2.3 Updating the Information.

As stated earlier, the maintainability of the system is improved, and revision control of the links made easier, by authoring the hierarchical structures of the information space into MHAs. As a MHA is amended only the linkbases associated with the MHA needs to be 'frozen' and stored as part of the change process. In the same way, a copy of the document prior to the amendment is kept as part of the document change procedure. In addition, only the linkbase that has been affected by the change and not all of the linkbases associated with the MHA needs to be 'frozen', thus reducing even further the amount of information stored, after an amendment to a MHA. The method used is to carry out the changes off-line and then re-import the changed MHA back into the compiled system. If the change is not a global change, the author is responsible for identifying to which occurrences of the information the change applies. Alternatively, the author can also mark which occurrences the change does not apply to, if this is easier.

The issue of concurrency, when more than one author requests to update a node, document or MHA at the same time, is handled in the same way as a paper-based system. That is, no two people can edit the same document at the same time. This is a simple matter of configuration control. The Document/MHA is 'checked out' as being authored when the change-note is being approved.

Configuration control can also solve the problem of when a shared document is updated. For example, when a modification takes place on a drive unit and there are a number of instances of that drive unit, but the modification does not effect all of them. A new MHA is created for the modified drives. This will reference the updated documents plus the unaffected documents that are still shared with the unmodified drives. The reason a new MHA is created is that this is the smallest granularity that makes a physical object or concept unique.

4.2.4 Dealing with Legacy Paper Information.

Authoring industrial hypermedia applications, using information that is in an electronic format and when using the above strategies, is a relatively straightforward task albeit a tedious one. However, in many industrial environments, documentation, especially manuals from Original Equipment Manufacturers (OEMs) are still in paper format. It was

therefore necessary, for viewing and integration into the system, to convert the information held on non-electronic media into an electronic format. However, once the process of converting a text document into an electronic format is completed, the documents are easier to edit and update.

The scanning process can be time consuming and hence costly. The length of time required is largely dependent on the quality of the paper documents, the software and hardware used. The largest portion of time was spent checking and correcting the information after conversion. Hence, it is important to obtain the 'master copy' of documents and not photocopies, as this will affect the time and cost of the conversion process and the quality of the electronic documents.

Where the documentation is of poor legibility it is easier to enter the information manually i.e. retype text documents. In the case of poor quality drawings it is often more cost effective to redraw or trace the drawing, using computer aided drafting, rather than scanning the documents to obtain the electronic version.

Whether by raster-vector conversion or manual entry (retyping, redrawing), when a document is converted to electronic format, in effect it becomes an updated document and therefore should be subject to the same quality control procedures as any other updated document.

Where forms are to be used in the electronic system, it may not be sufficient just to scan the details into electronic format, as data entry is required. The method used to produce the form will depend on its use. If the form is for information only, a simple template can be written for the form, the users then call-up the template, fill-in the details and e-mail the form. However, where forms are used for data entry and the data used in subsequent operations, use of a database or spreadsheet is more applicable. Other programs can then access the information for further manipulation, i.e. producing charts, report, etc.

4.2.5 Compatibility between Different Electronic Legacy Systems.

As the volume of electronic information increases within an organisation, there is a need to share information between disparate computer systems [Barron 97]. To enable compatibility between different word processing applications, the use of intermediary

formats such as, Rich Text Format (RTF) have been made. In addition, Word 97 was able to import the RTF format for further processing using macros. However, there can still be problems with using intermediary formats. For example, tables do not always translate correctly, especially where text that has been arranged using tabulation, as the tabulation settings are often different between packages.

The intermediary format used for technical drawings was the Data eXchange File format (DXF).

These formats were chosen for the following reasons:

- The files are readable in a read only viewer, and therefore cannot be changed without the correct permissions and loading the original application package.
- These are well-used standards and most modern systems will have the facility to convert documents into these formats.
- Viewers for these formats are readily available in Microcosm.

When authoring technical drawings in AutoCAD, use can be made of the ability to define blocks. Short yet unique descriptive names were used for each block. As the link is on the name (or attribute) of a block and not on a physical location within the drawing, when the drawing is updated and the block is moved, the link information need not be altered.

Unfortunately, it is not so easy to solve the problem of re-linking with digitised raster images as a component within the image is represented by a collection of pixels bound by a set of rectangular co-ordinates. If a drawing is updated, and an item moved, the link will need to be updated.

While it is now common for an organisation to now use a client/server network for most of the general systems, many will still use mini or mainframe computers to handle vast amounts of data. These are not necessarily in the most convenient format. However, most common database application will have a programmable interface. The author can use this to extract the information for the user to view, and with some extra work enable the user to interact with the data.

4.2.6 Automatic Dissection of Large Electronic Text Documents.

Paper documents have to present information within the page size of the document. To ensure this, significant time and effort is spent on the formatting and pagination of documents, for example ensuring that images do not span across page breaks. This is not a problem in electronic documents as the concept of page size is lost. However, reading large electronic technical documents by scrolling through the pages can be difficult, especially if the text refers to tables or technical drawings elsewhere within the document. Similarly, engineering drawings are often drawn or conceptualised as one large drawing, then with careful drafting, dissected in to small drawings for use in maintenance, installation, commissioning, etc.

While new or amended documents can be written so that they consist of several small files, enabling the users to effectively access the information required, it is necessary to dissect the existing large documents into smaller sections or nodes. These smaller nodes contain a reasonable sized chunk of information, so that the nodes will make sense in their own right. In practice, nodes vary in length, equivalent to a large paragraph through to a section of several screen lengths. This not only enables users to access the information they need easily, it also gives the author flexibility in laying out the screen for the novice user [Wills 97].

An example of the automatic 'dissecting' of a manual using macros has been completed. The manual used was an Eurotherm 590 series manual [Eurotherm 96]. The original document was created using a template and consisted of 24 chapters, 320 pages. The RTF viewer does not display the headers and footers of a document, so the concept of a page is lost when viewing electronically. The information contained in the header and footer therefore needs to be 'attached'. A file was appended to each section giving the company logo, company name and title of the document. In addition, it is possible to include common navigation buttons into this attached file. It has been found that caution was needed when adding buttons. If the buttons are too specific in nature they may cause problems with information reuse.

Dissecting long documents into smaller sections can have other advantages. For example Salton et al [Salton 94] have shown that by dividing the articles of an encyclopaedia into

sections and subsections, each identified by an appropriate section heading, a query can be successfully refined.

4.2.7 Automatic Explicit Link Generation.

The largest cost in producing a hypermedia application is the authoring process. This results from the time spent by a person experienced in the topic area, selecting and collating the information, and then manually linking the data into a cognitive and pedagogical structure that is easy to navigate [Crowder 97]. Therefore, to reduce cost, the authoring process must be automated, thereby reducing the time required by the 'expert' to link the hypermedia application.

The majority of authoring effort is spent on producing structural and explicit links, in an almost administrative role, to link -

- The table of contents (or index) to the relevant section.
- A list of tables (or figures) to the relevant table (or figure) and their reference in the text.
- Explicit references to other procedures, data sheets, etc, be it on the local system, or on the World-Wide-Web.

Therefore, the majority of these links can be automatically generated using macro languages available in many modern word-processing packages. The hierarchical structure of many technical manuals and procedures comes to the aid of the industrial author, when deciding on what to automatically link and where to dissect the manuals. As most chapters, sections, and subsections are formatted using heading styles, or distinguished from the main text in some way, i.e. numbered or in bold or of a different size font.

Macros have been written using Visual Basic for Applications in Microsoft Office to automatically link a large existing manual that has been dissected into smaller nodes, by using the method described in section 4.2.6. This enables a user to access the major section of a document directly, without having to go to the contents or index page, with little or no authoring input, again reducing the time and cost of authoring. Automatic generation of links is simplified by the use of templates, procedures and guidelines for construction of the documents. These guidelines, procedures and templates are a result of the design stage. In practice, several templates, procedures or guidelines are required (i.e. manuals, memos,

reports, specifications, etc). In many companies, these will already exist, either as part of the company's quality procedures or just good practice, as they improve efficiency and encourage consistency. The procedure for automatically dissecting the Eurotherm manual and creating the structural links is shown in Figure 4-5. Table 4-1 summarises the results of an experiment to compare the time taken to dissect and link an existing electronic manual automatically using the macros and manually using an experienced author.

A4 Pages	Number of links	Guided tour	Method used	Time Taken
143	315	Yes	Manual	More than 4 Hours
320	445	Yes	Automatic	Less than 3 minutes

Table 4-1 Comparison of the time taken to author a MHA automatically and manually.

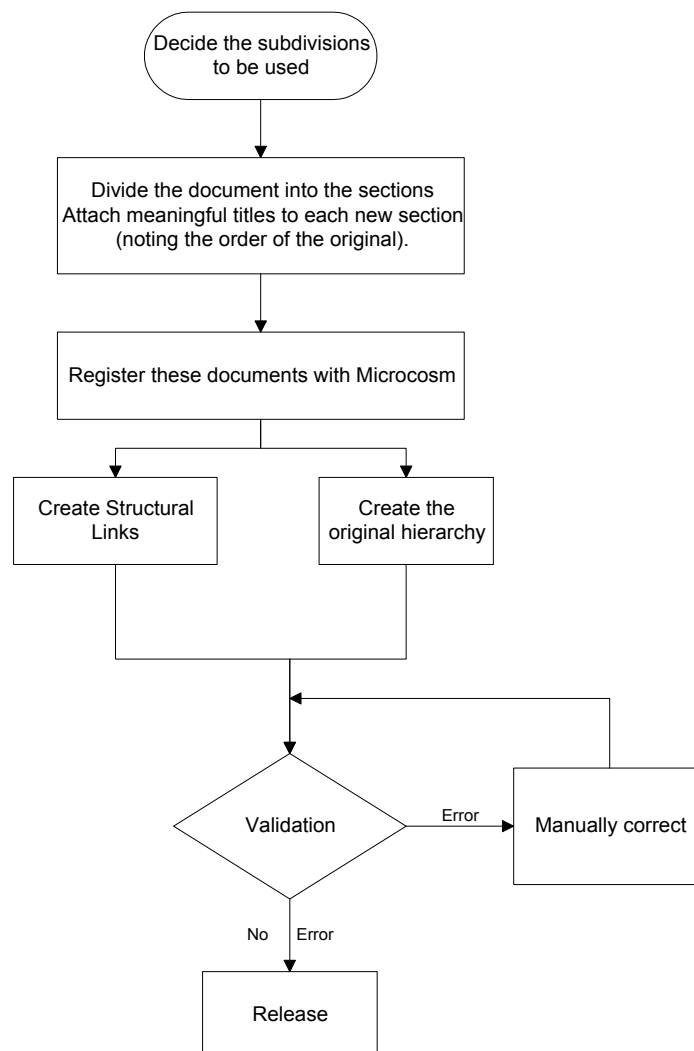


Figure 4-5 The flow diagram for automatically dissecting electronic manuals into useful size nodes and creating structural links.

The following areas were included in the comparison of the timings:

- The time taken to actually cut, paste and save the new section into RTF format (with the appropriate title).
- The time taken to produce the structural links.
- The time taken to produce the guided tour.

To ensure that comparisons of timings for automatic and manual production of structural links and dissection of the manual are valid, the following were not included:

- The time taken to decide how to dissect the manual into meaningful sections and deciding on the titles to be given to each section. As there is no time difference between manually and automatically carrying out this task, there is no time saving involved.
- The time taken to check and correct the process. Although a comparison of the number of errors is worth noting, the manual linking rapidly becomes tedious and consequently more errors are produced.
- The manual production of the appropriate link base and logical types in Microcosm, as the time taken is the same whether manually or automatically linking the application.
- The writing of the macro to automatically dissect and structurally link electronic manuals. These macros should be readily available to the author as a result of the design process. In addition, the time taken to write and test the macros only becomes an issue where the numbers of documents are small in size and quantity.

The advantage of this method over those reported [Carr 94], is that the authors are not required to do anything different from their normal task. All that is required is that they have used the functionality of the word-processor. In addition, the macro only requires the skills of a non-specialist programmer, i.e. an engineer that can write or record a basic macro.

4.3 Summary

This chapter has presented the general methods of authoring, and highlighted some of the problems faced by the authors of hypermedia application. Industrial hypermedia applications are typically classed as large-scale hypermedia applications due to their size and complexity. The areas that require special consideration are the scalability and reuse of information, the maintainability of the hypermedia application, and the cognitive burden to the author.

The largest cost in producing a hypermedia application is the authoring costs. Hence, the industrial authoring methodology given in this chapter has demonstrated that by using modern word processing packages the majority of the structural links can be automatically produced. Using the hierarchical structure of most technical information facilitated the concept of mini-hypermedia or modular applications to be developed. Using MHAs allow the complex application to become more manageable, enables the system to be scaled, encourages reuse of information and reduces the cognitive burden on the author.

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Chapter 5.

The Developed Hypermedia Application.

An industrial strength hypermedia application has been developed using the design and authoring methodologies presented in this thesis. Although dedicated to one manufacturing area, it is able to demonstrate the concept of a factory wide hypermedia enhanced information system. The application was developed for the case study environment presented in chapter 2, the Supertension Sheathing line at Pirelli Cables. The purpose of this chapter is to present those aspects of the research that enabled the factory wide hypermedia application to be developed. In addition to presenting the details of the application and the navigational tools used, this chapter also presents the research into the authoring environment, link clusters, interfacing with the process line and interfacing with the factory network. This chapter also examines if the methodologies used to produce the hypermedia application meet the requirement specifications.

5.1 The case study hypermedia application.

The Pirelli case study's information resource base, as of August 1999, comprised over 822 nodes in twenty-six MHAs. This equates to 642 Mbytes of information. Over 3500 structural links were produced and held in forty-five different linkbases, with an additional 1000 generic links held in a further thirty linkbases, and over fifty clusters. In addition, there are eighteen compute-link linkbases, and fifteen guided tours. The application is summarised in Table 5-1.

	Original Media	MHAs	Nodes	Structural Linkbases	Generic Linkbases	Guided Tours
<i>Pirelli Cables</i>	Word, Excel	Forms/work sheets	29	1	2	
	Video, Digital images	Training documents.	89	2	1	1
	Microfiche	Technical instruction	11	1	1	1
	Paper	Check lists	4	3	1	2
	Databases					
	Video	Drawings/Photos	153	2	1	0
<i>Eurotherm</i>		Unit Structure	28	2	1	0
	Word, DXF, Bitmaps	Drive Manual	141	1	1	2
	Word	Autoflange (scanned in),	8	1	1	1
	Bitmaps	Caterpullers	65	4	1	0
	DXF	Cleaning station	8	2	1	0
<i>Nokia-Maillefer</i>	Paper	Crosshead (scanned in),	12	1	1	1
		DC cabinet	3	2	1	0
		Extruder (scanned in)	27	3	1	2
		GE Head	5	1	1	1
		Installation (scanned in).	37	2	1	0
		PLC Program	53	1	7	0
		LCU Extension	25	2	1	0
		Line Control Unit	142	2	1	2
		Stripper Extruder	24	1	1	0
		Siemens motor.	5	1	1	1
<i>Siemens</i>	PDF	Seimens PLC	5	1	1	0
	Paper-documents					
<i>Santasalo</i>	Paper-documents	Santasalo Gear box	1	1	1	1
<i>Hypermedia specific</i>	RTF, Bitmaps, DXF	Menus/Help	15	8	1	0
		Totals	890	45	30	15

Table 5-1 The application resource base

5.2 Authoring Environment.

In order to establish the utilities required to ease the authoring of an industrial environment, an appraisal of the Microcosm system, taking account of the requirements for FIRM, took place early in this research. Most of the observations and ideas to improve the authoring environment were specific to the industrial requirements, rather than general hypermedia authoring requirements, and were deemed application specific. Therefore, to enable an application for the whole factory to be constructed, a wrap-around authoring environment was developed that used the Microcosm system at its core, yet enabled extra linking mechanisms and utilities specific to an industrial strength hypermedia application. The research presented in this thesis, set the engineering requirements, guiding the system development and designed tools to aid the user/author in an industrial environment.

The key features of the developed authoring environment are that it enabled:

- Access control to meet the requirements for a documentation control system, different levels of system accessibility was given depending on who logged into the application.
- The compilation of the MHAs into one application.
- Control of the importing and updating of MHAs. Each modified document was uniquely identified, and the date logged for change control, who the change was authorised by, who re-linked the document, and the change note number. The change control did not replace the company's own documentation control system or archive any obsolete documents, as this was carried out by Pirelli. It did however record, what had changed, and which linkbases and documents were effected.

The use of electronically sourced documentation was a considerable asset. However time was still required to structure the documents, in order to make them suitable for the hypermedia application. This was especially true for engineering drawings, where blocks were not used in the CAD drawing, and hence links could not be made on items within the drawing.

5.3 Link Clusters

Microcosm allows the user to navigate by a number of different layers of link mechanism [Heath 94], as follows:

- The Specific link is an association made from a particular object at a specific point in a specific document that connects to a particular object in a destination document. If the specific link is made visible to the user at all times it is called a button.
- The Local link is an association made from a particular object at any point in a specific document that connects to a particular object in a destination document.
- The Generic link is an association made from a particular object at any position in any document that connects to a particular object in a destination document.
- The Compute links. These links are dynamically computed when requested. This involves building an inverted index of all the desired documents before the system is used and using standard information retrieval similarity calculations, to match the vocabulary of the documents and offering the user links to the best matches.

The open architecture also allows different processes to be incorporated into a hypermedia application. The processes range from simple link creation and search algorithms to dynamic link creation, such as information retrieval and rule-base algorithms. The advantage of keeping the links separate is that data remains accessible to the original application that created it. Users are free to continue to manipulate data free from artificial constraints created by the system [Heath 96]. A final advantage of link separation is the facility to process the links. Authoring effort may be considerable reduced in open hypermedia systems by making use of such facilities as generic links and computed links. This system can be applied to any homogeneous file system, that is, any system on which all the files may be accessed and processed by the user's workstation

Using the linking mechanism available in Microcosm, the MHAs can be linked together to represent physical structure and pedagogical or conceptual themes. In addition, a higher level of linking that would link abstract concepts was required. This led to the notion of Link Clusters. A link cluster expands the idea of using generic links in Microcosm, to link a concept together. For example, for each document containing information about the item, a generic link was defined to it where the source anchor was the *name* of the item as it appeared in the documentation (e.g. *E3906*). This allowed all of the relevant information to be accessed from any occurrence of the name. This also included drawings where textual names were added to an area within the image. To extend the set of documents contained within the cluster, all the author needs to do is create another generic link with the same name in the destination node. This had the advantage that it was easy to implement.

However, there were several drawbacks with this approach. The problem with using generic links alone, is that: -

- It was difficult to maintain in that using generic links formed a primitive cluster made up of a collection of links. Therefore, to edit the cluster involved finding and changing each of the links.
- The generic link method was limited by having only one method of entry into the cluster of links. For example, if all the entries into a cluster were keyed to the name *E3906*. Yet at the same time *E3906* was also referred to by another name. It was impossible to build a cluster that was able to encompass both representations.

Hence, a link cluster was developed that solved these problems. This was achieved by making the cluster an object within the information system. Making the clusters first class objects allowed: -

- Access control lists can be attached to the clusters, allowing the author to control access by specifying an arbitrary list of permissions for users and/or groups.
- Multiple source anchors (names), some of which can be generic and hence content free, that is referenced by other clusters.
- Easier maintenance of the cluster.

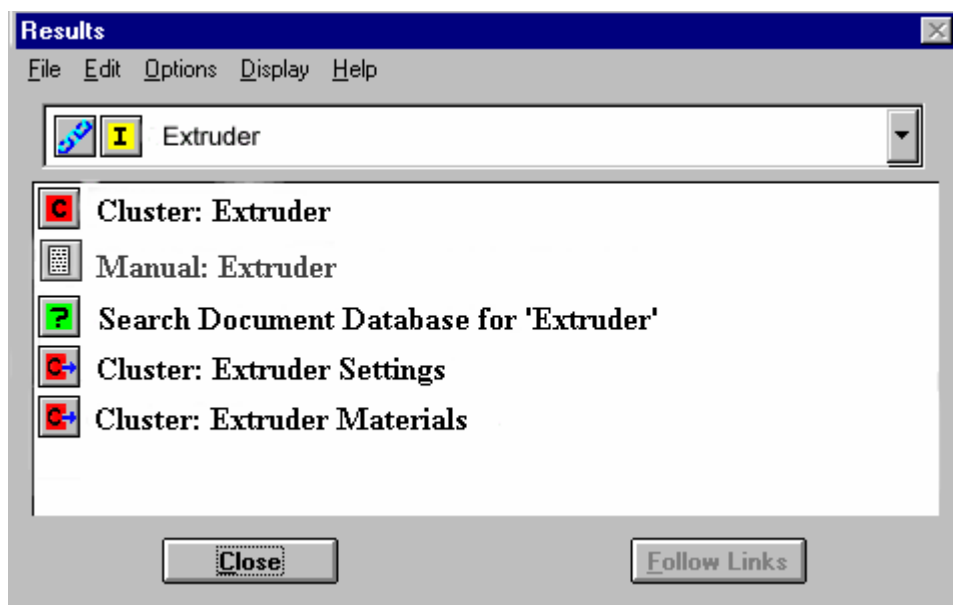


Figure 5-1 The Cluster Interface.

This model of link clustering has been implemented within the authoring environment [Heath 99], allowing a hypermedia author to build complex relationships between the various MHAs using high level terms represented by these link clusters. The users were

able to navigate the information using the clusters, providing an additional method for locating and browsing the information space. As an example, the interfaces in Figure 5-1 show the options open to the user via the extruder cluster. The user can study the manual, search for other documents containing the term 'extruder' or view other related cluster called extruder settings and extruder materials. The major advantage of the clusters is the ability to cluster prior knowledge. That is, the ability to group information for a specific task or area of interest.

5.4 Navigational tools.

The initial method of navigating the application was via menus and the toolbar. Following start-up of the application the users are presented with a title screen of the list of documents they may want to browse depending on their job function. The main index screen (see Figure 5-2) allows the user to follow links or clusters to the information. The toolbar (see Figure 5-3) was used as the main means of navigating the information space.

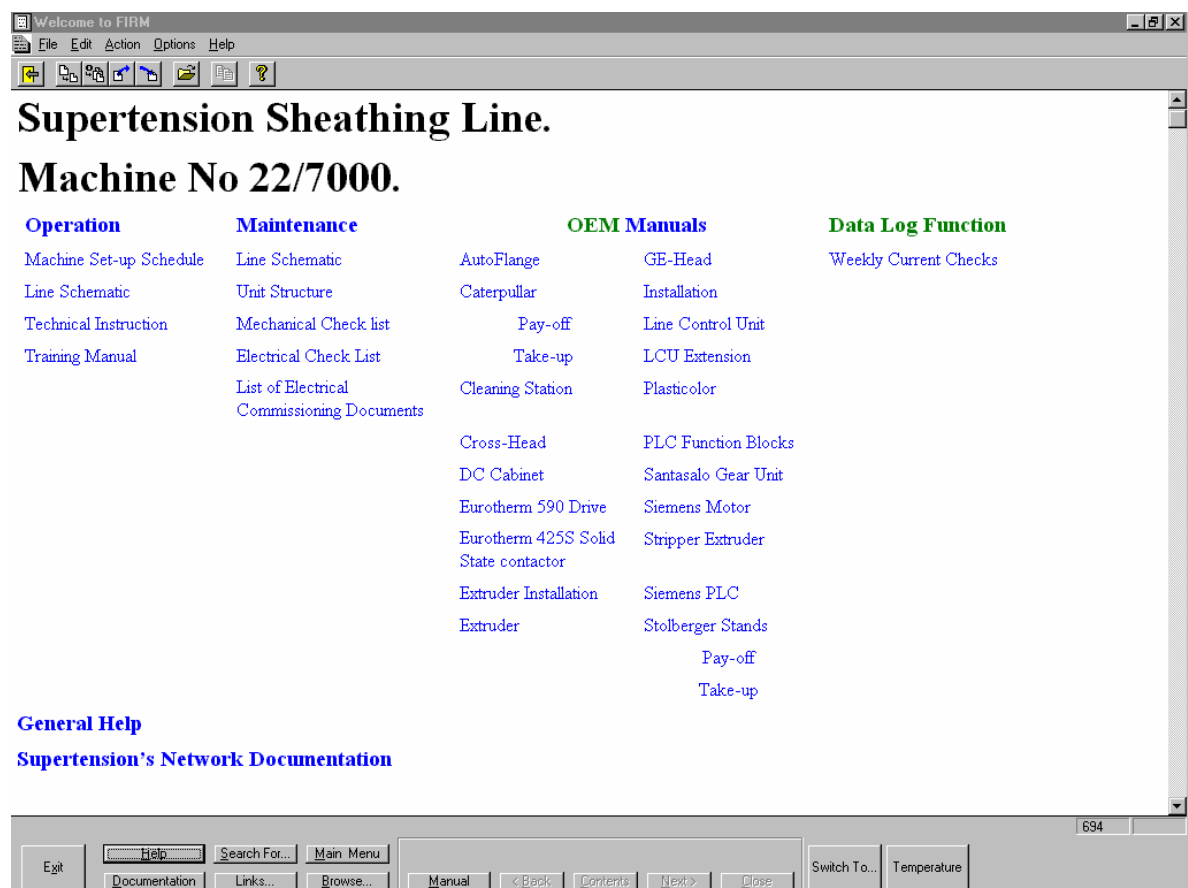


Figure 5-2 The main index page

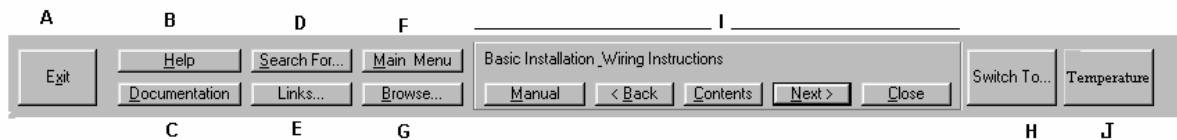


Figure 5-3 The Toolbar showing the Hot-keys

The tool bar allowed navigation by presenting the user with 'Hot Keys':

- A. Exit: The exit hot key will shut down the application and return to the operating system.
- B. Help: Will supply help for the Process Line
- C. Documentation: Provides a list of the most useful document clusters.
- D. Search for: This key allows the operator to search the compute linker for key words.
- E. Link: This brings up a follow link dialogue box.
- F. Main Menu: Closes all windows and returns to the main menu.
- G. Browse: Brings up the 'Select-A-Document' window, this window gives access to Microcosm's Document management system.
- H. Switch To: This hot key lists the open file allowing the user to switch between them. This is used to bring documents that are hidden behind other documents to the front.
- I. Page turning buttons. This group of hot-keys is used to control the interface whilst a manual is being displayed. It allows the user to cycle through the nodes using the back and forward keys, display the main content page using the content key, close the manual using the close key. The user is also able to get a list of manuals by selecting the manual key. In addition the title of the chapter and the section heading are also displayed, in Figure 5-3 the title is '*Basic Installation_Wiring Instructions*'.
- J. This button connects to a visual basic program that monitors the PC input buffer for fault codes, see section 5.5.

5.5 Interfacing with the process line.

In order to achieve the concept of a factory wide information resource, the system was required to communicate with, and respond to, other external information resources. In order to demonstrate this concept it would have been necessary to carry out a slight modification to the PLC program in order to establish communication between the PLC and a PC. The Pirelli management team felt that this would represent a significant risk to the recently refurbish process line. Hence to demonstrate the concept of communicating at minimal risk to the manufacturing line, the system shown in Figure 5-4 was developed:

- The hypermedia application was installed on a computer and connected to the Pirelli Intranet. The computer was located on the factory floor adjacent to the operator's main control panel.
- A PLC based monitoring system, shown in Figure 5-5, was developed for the cleaning head station. The unit incorporated a PLC from the identical family as used on the line. The PLC was installed adjacent to the production line and monitored a number of extruder head temperatures, whilst the extruding head was located in the cleaning station.

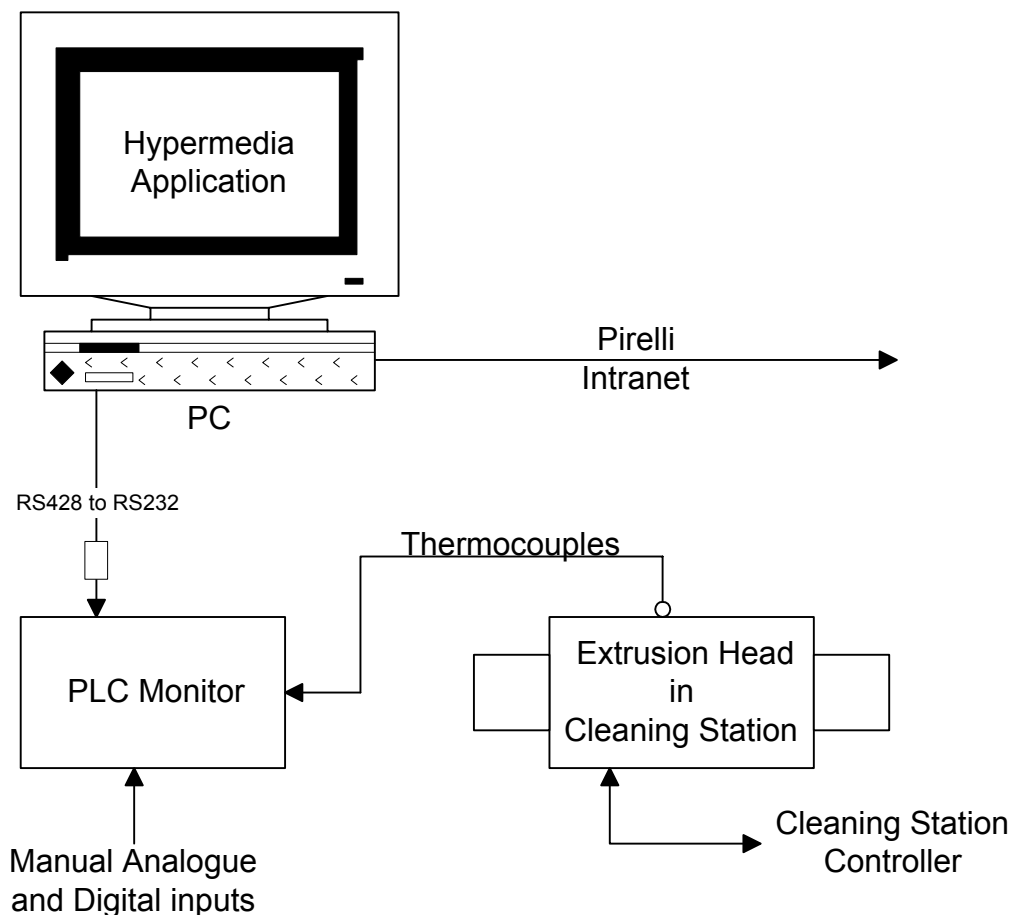


Figure 5-4 The interface to the application for the factory.

On the process line a central PLC monitors the operational state of the production equipment, and 'flags' any error. Therefore, it was proposed to use these 'flags' to have diagnostic information, that is circuit diagrams, fault finding trees, etc, pre-loaded, ready for the maintenance technician to carry out the required fault finding tasks.

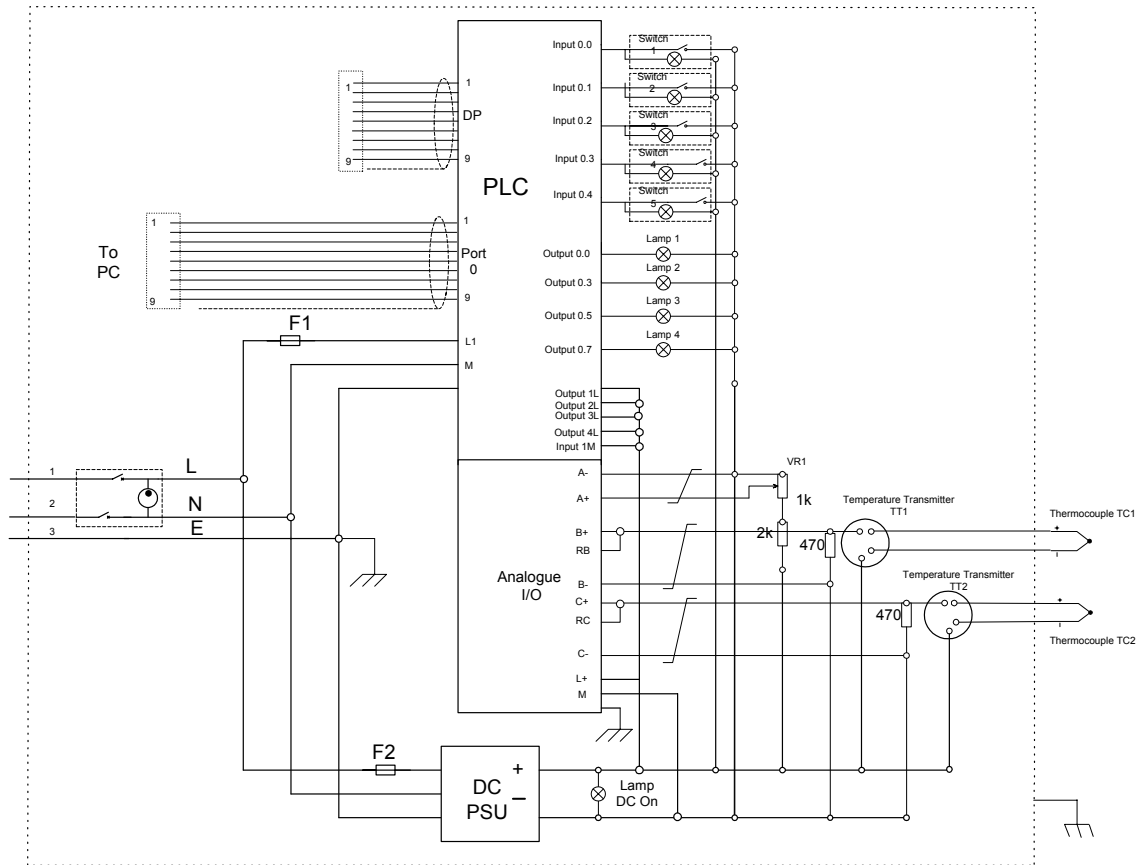


Figure 5-5 Electrical Schematic for the PLC mirror.

The function of the developed PLC monitoring system was to emulate the Line PLC's process for detecting a fault condition and transmitting a fault code to the hypermedia system. The hypermedia system then responds to the fault code by displaying a description of the fault and a list of recommended documents to view. Simulated fault codes could be activated by the push buttons on the PLC monitoring system. A number of analogue inputs were possible including thermocouples and a user adjustable input.

The PLC's program to carry out the transmission of fault information involves only eight ladders adding 600 micro-seconds to the initial scan cycles and only 400 micro-seconds for subsequent scan cycles. This excludes the transmission time, as the scan cycle of the PLC allows the main program to continue as the communication to the hypermedia application takes place in the background. As a demonstration, twelve fault codes were programmed into the PLC.

A visual basic program was written to monitor the input buffer of the PC, for 'flags' or fault codes from the PLC. This program was integrated into the toolbar and displayed the temperatures and the value of the dial gauge, Figure 5-6. On detecting a fault code, the

visual basic program communicated with the hypermedia system to display an alert document. Each document consisted of a description of the fault, actions to rectify the fault and sources of appropriate information i.e. manuals, drawings, photographs, etc, as shown in Appendix B.

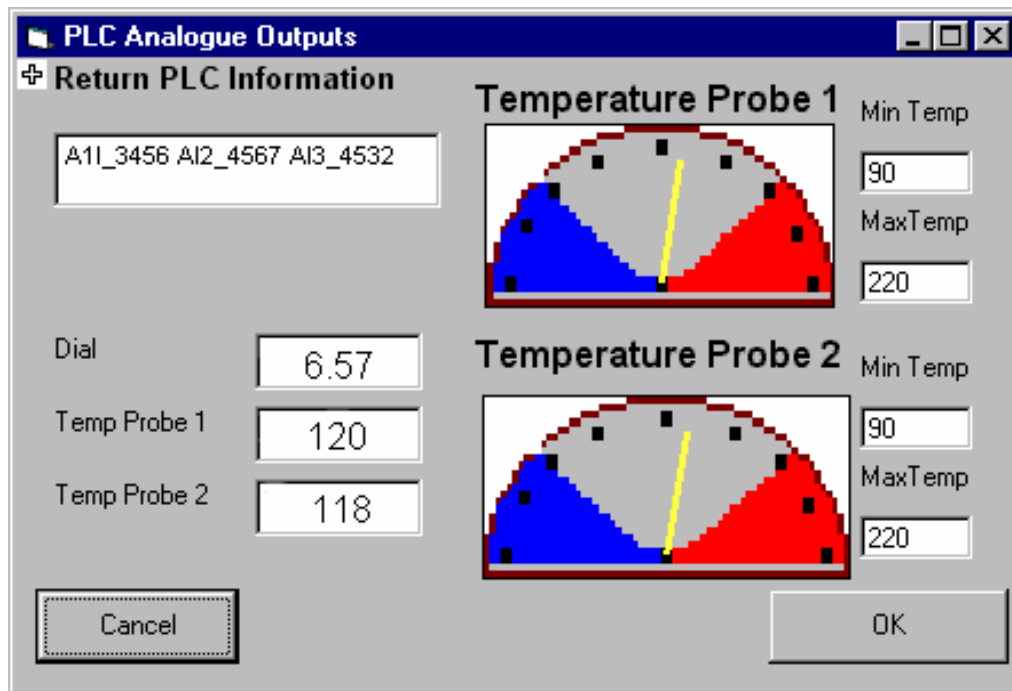


Figure 5-6 The PLC interface

5.6 Interfacing with the factory electronic resources.

The PC with the hypermedia application was connected to the factory network, in a similar manner to other PCs within the factory, see Figure 5-7. The PC was used to connect to the other servers within the network, and the users were able to read any network documents they had permission to read. As described in the contextual review, Appendix A, each area has a designated virtual F drive. A separately developed program enabled the system to read the directory structure, file names within the directors, and automatically generate links to these files. This allowed the management to put documents into this structure for the operators to act upon. Typical documents where the latest version of the set-up spread sheet, and additional information that would normally be given on single sheets of paper. This ensured the operators had the latest set-up and process information and that additional information did not get lost.

Each process line has a unique company numeric identifier, as described in Appendix A. The plant on each process line is also uniquely identified with an additional four-digit number. All information relating to that plant is stored under the appropriate unique numeric identifier, i.e. drawing lists, materials lists and piece part information. This information structure is referred to as the unit structure. The unit structure consists of a number of b-tree databases and a textual users interface, within POMS (Production Operation Management System). The hypermedia system interfaces with the databases and presents the user with the information, in a similar format to that of POMS. However, rather than having to log in and out of different systems the user can navigate seamlessly between the hypermedia application, the virtual F drive and POMS.

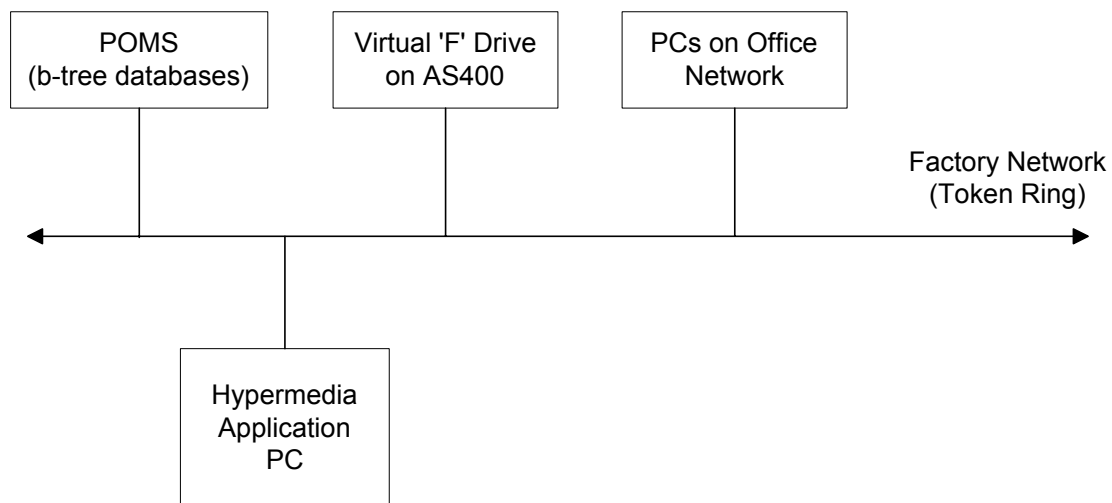


Figure 5-7 The interface to the factory network.

5.7 Does the Methodology developed meet the requirements?

The authoring and design methodologies were developed for a large-scale industrial hypermedia application, against the requirement specification presented in Chapter 3. Therefore, when the Christodoulou et al. evaluation method [Christodoulou 98], used in Chapter 3, is re-applied to the methodologies and authoring environment, it is not surprising then, that they satisfy the requirements perfectly, as shown in Table 5-3 and Table 5-4. As the requirements criteria were judged to be fulfilled by those who designed and implemented the application, investigation is required into the significance of any error in their judgement. Hence, the judgement used in the evaluation requires testing for sensitivity to error. That is, would the evaluation still yield the same result if the criteria

were stiffened (raised) or if the evaluation score assigned to the methodologies was reduced?

As stated earlier, the authoring methodology is an integral part of the design methodology, hence these should be viewed as a complete methodology. In addition, the evaluation method used by Christodoulou et al. for assessing a hypermedia application development and management systems (HADMS), assess both the design methodology and the authoring environment. Hence, for brevity the combination of the developed methodologies and authoring environments (presented in this chapter) are simply referred to as FIRM in Table 5-3 and Table 5-4.

The same method as used in chapter 3 was used to calculate the scores in Table 5-3 and Table 5-4. The methodologies and environment were rated as: - not supported assigned the value 0; poor support value 1; acceptable support value 2; or fully supported value 3.

The score for each individual HADMS was calculated by summing the scores for each of the applicable criteria. These scores are then normalised by dividing each of the system scores by the score from the industrial application criteria. The results are summarised in Table 5-2. From Table 5-2 it can be seen that the methodologies and environment used in this thesis fit the criteria required of an industrial application. The evaluation process described in this chapter is to be taken in association with the user evaluation to assess the suitability of methodologies for the industrial environment.

	Industrial Requirements	FIRM	OOHDM	RMM	HSDL	HSM	Strudel	Story	FP
Methodology (criteria A-E)	1	1	<i>0.768</i>	<i>0.429</i>	<i>0.554</i>	<i>0.625</i>	<i>0.393</i>	<i>0.482</i>	<i>0.375</i>
Environment (criteria F-H)	1	1	-	<i>0.259</i>	<i>0.444</i>	<i>0.370</i>	-	<i>0.926</i>	<i>0.555</i>
Overall	1	1	<i>0.518</i>	<i>0.373</i>	<i>0.518</i>	<i>0.542</i>	<i>0.265</i>	<i>0.626</i>	<i>0.434</i>

The scores in italics are derived from the original evaluation by Christodoulou [Christodoulou 98].

Table 5-2 Normalised results of the evaluation.

	Criteria	Requirements		FIRM	
		Evaluation	Score	Evaluation	Score
A	Common				
A1	Structural constraints.	Required	3	Fully Support	3
A2.	Design evolution	Highly Recommended	2	Acceptable Support	2
A3.	Reusing and tailoring.	Required	3	Fully Support	3
B.	Conceptual Data Model Design				
B1.	Basic hypermedia support.	Required	3	Fully Support	3
B2.	Multimedia support.	Required	3	Fully Support	3
C.	Abstract Navigational Model Design				
C1.	Semantically.	Desired	1	Poor Support	1
C2.	Composites.	Highly Recommended	2	Acceptable Support	2
C3.	Semantically typed links.	Required	3	Fully Support	3
C4.	Link attributes.	Required	3	Fully Support	3
C5.	Bi-directional links.	Desired	1	Poor Support	1
C6.	Anchors embedded in node content.	Required	3	Fully Support	3
C7	Internal link update mechanisms,	Required	3	Fully Support	3
C8.	Automatic creation of links among nodes,	Required	3	Fully Support	3
C9.	Global and local views,	Required	3	Fully Support	3
C10.	Node and link participation in different views.	Required	3	Fully Support	3
C11.	Access structures.	Required	3	Fully Support	3
C 12.	Personalization features (user profiling).	Highly Recommended	2	Acceptable Support	2
D.	User-Interface & Run-time Behaviour Design.				
D1.	How interface objects map to navigational objects.	Not Required	0	Not Supported	0
D2.	Specification of run-time behaviour to interface objects.	Required	3	Fully Support	3
D3.	Synchronisation of interface objects,	Desired	1	Fully Support	1
D4.	User-defined instantiation.	Highly Recommended	2	Acceptable Support	2
E.	Implementation issues				
E1.	Dynamic content.	Not Required	0	Poor Support	0
E2.	External storage systems.	Required	3	Fully Support	3
E3.	Simplicity.	Required	3	Fully Support	3
	Methodology		56		56

Table 5-3 Methodology Criteria Requirement for an industrial application

	Criteria	Requirements		FIRM	
		Evaluation	Score	Evaluation	Score
F.	General				
F1.	Client/server distribution.	Not Required	0	Fully Support	0
F2.	External tools.	Required	3	Fully Support	3
F3.	Extensibility	Required	3	Fully Support	3
F4.	Importing.	Required	3	Fully Support	3
F5.	Content-based information retrieval mechanisms.	Required	3	Fully Support	3
F6.	Structure-based information retrieval mechanisms.	Desired	1	Poor Support	1
F7.	Supporting utilities.	Not Required	0	Fully Support	0
F8.	Quality testing.	Not Required	0	Not Supported	0
G	Collaborative				
G1.	Simultaneous multi-user access.	Not Required	0	Not Supported	0
G2.	Access control.	Not Required	0	Fully Support	0
G3.	Member activity tracking.	Not Required	0	Not Supported	0
G4.	Notification controls.	Desired	1	Poor Support	1
G5.	Versioning at the level of individual entities	Required	3	Fully Support	3
G6.	Annotations (private, workgroup or public).	Desired	1	Poor Support	1
G7.	Interactive collaboration:	Not Required	0	Not Supported	0
H.	User Interface (UI).				
H1.	UI of the design and implementation environment	Required	3	Fully Support	3
H2.	UI of the authoring environment,	Required	3	Fully Support	3
H3.	Intelligent user assistance,	Required	3	Fully Support	3
	Environment		27		27
	Overall		83		83

Table 5-4 Environment Criteria Requirement for an industrial application.

Using Table 5-2, for the new methodologies (FIRM) not to score the same or less than the established methodologies would require a thirty seven percent error in allocating the level to which the criteria was implemented. This is equivalent to rating 31 of the 33 non-zero scores one category higher than they should have been. However, for the methodologies alone, the error in scoring the criteria is only twenty three percent. This is equivalent to rating 13 of the 24 non-zero scores one category higher.

To test the sensitivity to error in assigning scores to the methodology and authoring environment, all the values of the scores were reduced to the lower category. Thus Fully Supported becomes Satisfactory Support, Satisfactory Supported becomes Poor Support and Poor Support becomes Not Supported. The score were recalculated against the industrial criteria. The results are summarised in Table 5-5 and shows that the new methodologies and authoring environment continued to score higher than the other HADMS for an industrial application.

	Industrial Requirements	FIRM	Story	HSM	OOHDM	HSDL	FP	RMM	Strudel
Methodology (criteria A-E)	1	0.589	0.482	0.625	0.768	0.554	0.375	0.429	0.393
Environment (criteria F-G)	1	0.741	0.926	0.370	-	0.444	0.556	0.259	-
Overall	1	0.639	0.627	0.542	0.518	0.518	0.434	0.373	0.265

Table 5-5 The normalised results after the FIRM scores were reduced.

To test the sensitivity of the criteria, all the criteria for an industrial application were raised to 'Required'. In addition, all HADMS were assigned their original scoring. The results are summarised in Table 5-6. As can be seen, even then the combination of methodologies and authoring environment described in this thesis give the best overall result.

	Industrial Requirements	FIRM	Story	HSM	FP	OOHDM	HSDL	RMM	Strudel
Methodology (criteria A-E)	1	0.778	0.472	0.597	0.389	0.736	0.528	0.361	0.347
Environment (criteria F-G))	1	0.500	0.741	0.296	0.519	-	0.241	0.148	-
Overall	1	0.659	0.587	0.468	0.444	0.421	0.405	0.270	0.198

Table 5-6 The normalised results after the criteria was stiffened.

From the above sensitivity analysis it can be seen that the proposed methodologies, described in chapters 3 and 4, and the environment described in this chapter satisfy the requirements of an industrial hypermedia application.

5.8 Summary.

This chapter presented the key features of a case study on industrial hypermedia application. The application used the general design and authoring methodologies presented in this thesis. One of the key features of the specific application was the new authoring environment. The authoring environment wrapped around the Microcosm enabling the requirements of documentation control and industrial environment to be met. Link clusters enable the prior information on tasks or topics of interest to be grouped together, allowing easier navigation of a large information space. A simulation of the Line PLC was used to demonstrate that the hypermedia application would respond to fault codes by giving the users helpful information. The hypermedia system also integrated into the existing information network, enabling the users to view additional information. The design and authoring methodologies and authoring environment were examined against a published set of criteria. Their ability to satisfy the requirements of an industrial hypermedia application was evaluated. The results show the methodologies and authoring environment to be the best for an industrial application. Within the terms of the evaluation, the results are robust. That is, they were not sensitive to error. These results are to be taken in context, as part of the overall evaluation of an industrial application.

Chapter 6.

Evaluation Methodology for Industrial Hypermedia.

This chapter describes the methods that can be used for evaluating an industrial hypermedia application. The chapter then draws these together to present the methodology that was used to evaluate the FIRM industrial hypermedia application.

The widespread introduction of hypermedia into an industrial environment is to a large extent governed by its acceptance by factory floor personnel. There is therefore a need to evaluate the effectiveness of the Human-Computer-Interaction (HCI) within the factory environment, along with the design of the user interface and navigational aids.

Any industrial application needs to present the users of the system with information that is clear and consistent [Crowder 96a]. For the purpose of the research a *user* is defined as any person who would normally have access to the information in the course of his/her daily work. Hence, it is essential that the evaluation of the hypermedia application takes place within the user's environment, and by appropriate end users [Yamada 95]. This needs to be reflected in the evaluation methodology.

Evaluation is concerned with the gathering of information about the usability (or potential usability) of a system, in order to improve features within an interface and its supporting material or to assess a complete interface [Preece 93]. Evaluation is closely linked with

design and development, and can occur at any time in the design and development cycle. The issues to consider when planning an evaluation are:- validity and reliability of data collection and analysis, biases, the scope of the information needed and amount of interference to the study caused by the evaluation itself (commonly termed ecological validity).

The aims of HCI evaluations [Preece 94] are to assess the:

- Speed of navigation through the system.
- Users ability to find the correct document or point in the document.
- Identification of the interface formats that cause problems or misunderstandings.

6.1 General Evaluation of Hypermedia Application.

In order to obtain meaningful results from the user evaluation, it is important that sound research methods are used [McNeil 90]. In addition, the methodology needs to consider the practical aspects of time and cost.

Due to the availability of resources and costs limitations, traditional experimental and usability-testing involving a specialist usability laboratory [Preece 94] were not an option for evaluating HCI in this research. Hence, in this section the various methods of evaluating an industrial hypermedia application, other than using a usability laboratory, are described.

In the context of developing hypermedia applications the meaning of the terms verification and validation can be determined by examining their use in the different, yet analogous domain, of software engineering [Lowe 99]. Lowe uses the definitions from the IEEE Standard Glossary of Software Engineering Terminology (IEEE Std 729, 1983):

- **Verification** is the process to determine whether the product conforms to the requirements specified in the previous phase. Thus, verification tries to answer the question "is the system built correctly?"
- **Validation** is the process at the end of the software life cycle in which it is tested whether the software conforms to the requirements specification. Thus, validation tries to answer the question whether the completed system is the correct one for the application.

There are essentially two levels of measurements in hypermedia: heuristics and metrics. A heuristic measurement is a rule-of-thumb; that is it is a qualitative measurement. Heuristics are often used to provide an indication of how to interpret a metric [Lowe 99]. A typical heuristic might be “if a MHA has a hierarchical structure deeper than 6 levels then it could be difficult for a user to locate information”. A metric results in an absolute figure on some scale; that is it is quantitative. Metrics can include things like the average number of links in an MHA, or the hours spent on authoring each MHA.

Much published literature on evaluating hypermedia applications focuses on application domains other than industrial applications. Those that do deal with the industrial domain use embedded link technology and focus on training or only provided empirical results [Greenough 98]. For example, Koshy et al [Kosky 96] investigated the effect of training factory floor operators to perform a number of tasks using a hypermedia application. Their results showed an increase in the knowledge learnt and a slight decrease in the time taken to perform the tasks when using the hypermedia system compared to paper-based information.

Rowley has carried out usability testing of software systems in the field [Rowley 94]. Although these were classed as field tests, they were carried out in the regional offices of their representatives, in the USA and Europe. Of the 13 lessons learnt in the paper, many may be explained by careful planning prior to carrying out the field test. The points raised by Rowley that are applicable to industrial hypermedia are:

- look for problems not related to the task scenario,
- be particularly sensitive to culturally influenced terminology. This is especially important when dealing with alternative names for the same item in an industrial environment.

6.1.1 Systematic User Evaluation (SUE).

Garzotto et al [Garzotto 97] have proposed a framework for the Systematic User Evaluation (SUE) of Hypermedia that basically combines inspection with empirical testing. The system can be divided into two phases:

- The Preparatory phase: This is an important process, that can be time consuming, in which the conceptual framework for the evaluation is completed. However, this process only needs to be carried out once.

- The Evaluation Phase: This is a mixture of ‘expert’ and user evaluations. The results of these evaluations are fed back to the designer for consideration

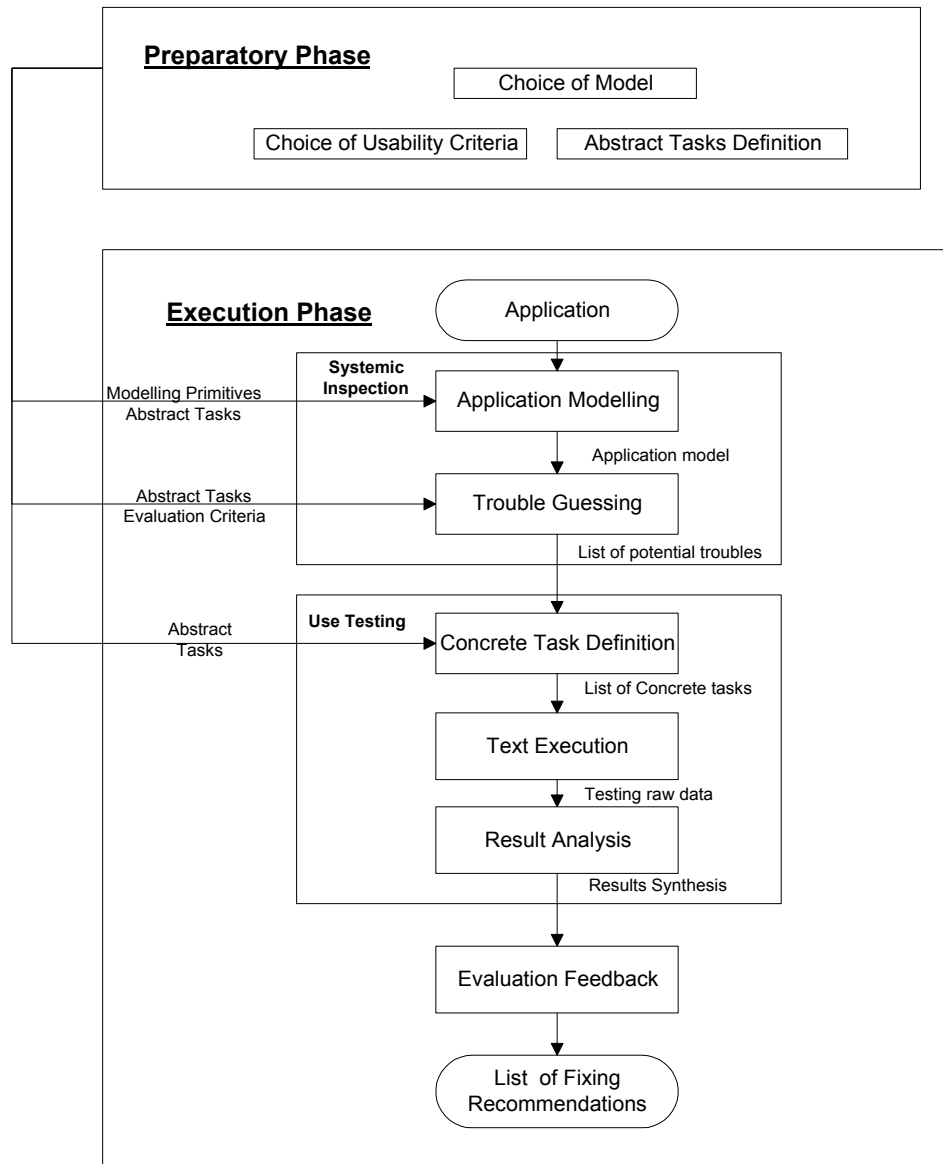


Figure 6-1 Systematic Evaluation of Hypermedia suggested by Garzotto.

SUE was originally designed with Hypermedia Design Methodology (HDM) and museum applications in mind. The details of the evaluation process as given in the literature [Garzotto 97] cannot be directly applied to an industrial environment. There are several reasons for this: -

- The evaluation process is heavily biased towards the Hypermedia Design Model, proposed by Garzotto et al [Garzotto 95].

- The resulting hypermedia application is used in an unrelated environment, that is it is based around a museum application compared with the industrial environment.
- The system has to respond to a different user base. The evaluation process was designed around applications that involved untrained users from the general public. Hence, the actual abstract task and evaluation methods in the execution phase are not applicable to the industrial environment.

The principles that can be distilled from the preparatory phase of the SUE approach are: -

- That the model primitives or design criteria need to be explicitly stated.
- The usability criteria of the application need to be defined.
- The definition of the abstract and concrete tasks needs to be defined.

Care needs to be taken when using these principles to ensure that the evaluation methods used will evaluate the issues involved in large-scale industrial applications, and that the language used is appropriate to an industrial environment.

6.1.2 Structured Expert Reviewing.

The resources available for the evaluation lends itself to Structured Expert Reviewing [Preece 94], in particular discounted usability evaluation. Discounted usability evaluation is a heuristic evaluation and was first proposed by Nielsen [Nielsen 89] and subsequently refined [Molich 90, Nielsen 92]. Discounted usability evaluation can be carried out with few resources, consisting of scenarios, simplified think aloud and heuristic evaluation to alleviate current problems by design-evaluate-design. The whole cycle needs only a few testers as any more do not produce any significant benefit. The discounted usability method uses small scenarios that can be easily changed, and as the ‘thinking aloud’ is carried out informally and therefore does not require psychologists. Only a few guidelines are required for the heuristic evaluations;

- Use simple and natural dialogue.
- Speak the user’s language.
- Minimise user memory load.
- Be consistent.
- Provide feedback.
- Provide clearly marked exits.
- Provide shortcuts.

- Provide good error messages.
- Prevent errors.

The advantages of this method are that the majority of errors can be found without having to waste users' time. However, the method does rely on the ability of 'experts' to judge the reactions of the user and hence not all the problems will be found. Nielsen has evaluated several sets of usability heuristics [Nielsen 94]. His aim was not to find the best set, but an amalgam of usability heuristics, in order to produce a set that would find the usability problems in a real system. The result was two lists of usability heuristics. The first covered 85% of the 249 usability problems found in previous case studies, while the second list covered 95% of the 82 serious usability problems. It is worth pointing out that the original set of usability heuristics that provided the most comprehensive coverage (82%) of the usability problems was the set by Molich and Nielsen used in this research. The evaluation they did included one more criteria to the original nine usability heuristics. This was 'Help and Documentation'.

6.1.3 Interviews and questionnaires.

Encouraging users to give their opinion, albeit subjectively during the design will ensure unusable, unnecessary and unattractive features are removed much earlier, more easily and more cheaply from the application. To ensure that the line of questioning is relevant to the issues under investigation, careful planning of the questionnaires and interviews is essential [Preece 94]. The general guidelines for producing a questionnaire are to keep the questionnaire short (about two A4 pages) and be careful when using different rating scales, as this can confuse some people. The main two types of interview technique used in this research were:

- Structured interviews: These have pre-planned questions, making it easier for the interviewer to follow and are much easier to analyse formally. However, they may not explore the individual's attitudes.
- Semi-structured: These can also be used to draw out information, in addition to obtaining answers to questions. However, care has to be taken not to ask leading questions that will give a particular response. Often a checklist is used to help guide the investigator. The checklist is only a guide and the interviewers are free to follow

interesting comments made by the user. This type of interview consists of open questions such as:

- ◆ How do you do it? What are the preconditions for doing this? May we see you work this product? Why do you not do this in the following method?
- ◆ What was the result of doing this? Do errors ever occur when doing this? How do you discover and correct these errors?

The focus when preparing questionnaires is in the preparation of unambiguous questions, with closed questions providing a choice of answers, or open questions allowing the respondent to freely provide their answer.

The type of closed question used in this research were:

- Three-point scale: - Yes, No, and Do not Know.
- Multi-point rating scale: - Novice to Expert.
- Likert Scale: - Strongly Agree to Strongly Disagree.
- Rank Order:- rank the choices in order of ease.

The questionnaires require careful planning and can be analysed using commercial packages such as SPSS or Excel. Before designing the questionnaire or analysing the results a null-hypotheses is required [Bryman 90]. This planning can be time consuming, however, even more time is wasted if questionnaires are incorrect and the evaluation has to be rerun.

6.1.4 Software metrics

Numerical measures of the products and processes of software development are called software metrics. Metrics can be misinterpreted and misused, hence it is crucial that the evaluators are clear about what is being measured, and just as importantly, why they are measuring it. To develop a matrix that will test what is required, a Goal-Question-Metrics (GQM) approach has proven to be particularly effective in selecting and implementing metrics [Fenton 97]. The GQM approach was first suggested by Basili et al [Basili 94]. The GQM approach provides a three-stage framework:

- List the major goals of evaluation.
- From each goal, derive a set of questions that must be answered if the goals are to be met.

- Decide what is to be measured in order to adequately answer the questions.

The hypothesis states what is being investigated. Fenton and Pfleeger describe a hypothesis as "*the tentative theory or supposition that you think explains the behaviour you want to explore*" [Fenton 97]. There are two hypotheses, the null (H_0) and alternative hypothesis (H_1). The null hypothesis assumes no significant difference between two methods, tools, techniques etc. The alternative hypothesis proposes that there is a significant difference. The distinction between the two hypotheses is a statistical one. The null hypothesis is assumed true unless the data indicates otherwise. Stating the null hypotheses is based on a principle that exploits a logical argument called *reductio ad absurdum*, or more commonly proof by contradiction [Singh 97]. If the difference between the hypothesis is unlikely to be brought about by chance, it is statistically significant. It is convention to use the 5% (0.05) probability level for statistical significance. The difference in significance level is not a measure of the magnitude of the experimental effect, i.e. a significance level of 1% or 0.1 % is not more real than one at 5% [Foster 98]. If the alternative hypothesis is non-directional, a two-tailed test is employed. However, if the hypothesis is directional, a one tailed test is used.

6.1.5 Prototypes and Case Studies

Prototypes and case studies are a preferable method of evaluation when the evaluators are unable to manipulate relevant behaviour [Fenton 97]. Case studies and prototypes can provide a cost-effective way of ensuring that methods and tools provide the desired results [Kitchenham 95]. In this research, the sister project and random selection approach was used when evaluating the hypermedia application: -

- Sister projects. These projects have similar variables to the ones the evaluators are planning to measure. For example similar application domains, implementation languages, specific techniques, or design methods.
- Random selection. The project is partitioned into parts; where one set of users use the new technique and the others use the current or another technique. Here the evaluation resembles that of a formal experiment, with randomisation and replication in performing the analysis.

6.2 Methodology for evaluating a large-scale industrial hypermedia application.

The sections above outlined the rationale and methods to be used in evaluating user interaction in an industrial environment. These can be developed to provide a generic solution to the problem of evaluating a large-scale industrial strength hypermedia application.

For the evaluation of a large-scale industrial hypermedia system, the evaluation takes place in five stages:

1. Contextual review of the factory working practices of the industrial environment, into which the application is to be implemented. The contextual review serves two distinct purposes. First for the purpose of the design phase, it assisted in identifying the information requirements of the users. Second, for the purpose of the evaluation phase it aids in identification of the working practices of the users, from which evaluation scenarios and procedures can be derived. The contextual review process is described in chapter 2.
2. The pilot application stage. At this stage, structured expert reviews are carried out using discounted usability engineering as described in section 6.1.2.
3. After a formal training program, the users were asked to fill in a questionnaire.
4. The users were asked to perform predefined tasks to evaluate the effectiveness of the case study application. These predefined tasks are measured as in section 7.1.4. Half the group carries out a number of tasks on the current systems first, while the other half of the group undertake the tasks using the new hypermedia systems. Then allow the groups to change around. After completing the tasks the operators fill out the questions, the results of which, along with the any data logged automatically by the system, are used to evaluate the application. The orders of the tasks are randomised to ensure that the task order is not unconsciously arranged to favour either system [Bryman 90].
5. As a longer-term evaluation, the attitudes and comments of the users are gathered as they use the application during their daily work. This is an essential part of the trials and will be combined with questionnaires and interviews to assess whether or not there is any change in the users' opinion of the system. This was achieved in this research by

repeating the time trial with questionnaires, six months later. Feedback from the users is essential. Therefore, some method of reporting is required. This can range from a logbook placed next to the machines to on-line forms. It is important to feedback the resulting corrective actions to the problems raised, to ensure the users' continual participation.

6.2.1 Choice of users.

As stated earlier, it is essential that the evaluation of the hypermedia application takes place within the environment that it is to be used, using the appropriate end users [Yamada 95]. In addition, the choice of subjects is vital to the success of any experiment [Dix 98]. Hence, when evaluating industrial strength hypermedia, different personnel are required for the stages described above. This is especially applicable to the expert review of the case study, where both the content and user interfaces are to be evaluated.

When evaluating the user interface, experts with computer science and HCI backgrounds should be used. When evaluating the content of the application it is advisable to use experts that are, or have worked, in an engineering environment, preferably connected with maintenance. However, as each organisation has its own culture, actual work practices and subtle changes in terminology, ideally personnel should come from the actual working environment when evaluating the content of the application.

The choice of users for the time trial will be the personnel from the factory-floor. Where a subgroup of users are to be used in the trials, they must be representative of the proposed users group, as a whole. That is, there is the same proportion of people in the sample group with the same technical abilities, computer skills, age distribution, etc, as there are in the workforce who are to use the hypermedia application.

6.2.2 Defining the evaluation tasks for an Industrial Environment.

This phase of the evaluation determines the what, in the what, how and where of the evaluation process. The choice of a model is to guide the analysis of the application and provide a common language/set of definitions for the abstract tasks. In this research, a new design methodology is used for the industrial environment, as described in chapter 3. The main primitives or design concepts that describe the essential features of the new

methodology are shown in Table 6-1. The usability evaluation of a hypermedia application can generally be divided into three main areas.

1. The general look and feel of the user interface. This will include dialogue styles, menus, shape of buttons, usage of colours, window design and the actions the operator has to perform i.e. click on the button with mouse.
2. Evaluation of the representation of the information structure. In this research, this includes the MHA structure, change control, access methods, general navigation features including any active media control, for example guided tours, video segments or animations.
3. Evaluation of the application specific information. In the case of this research, does it make sense? can the users follow a train of thought? contents of MHA, is information appropriately clustered/ are the drawings clear? etc.

The main issues to evaluate in the area of the general ‘look and feel’, are a function of the propriety software used to build the application. Information structure and information content are a function of the application domain. Therefore, the latter areas need to be specifically evaluated. However, intrinsic to the evaluation will be the ‘look and feel’ of the entire application. Special attention should be given to those areas of the interface specifically designed for the application, such as the toolbars and menus.

Primitives	Structural	Navigational	Presentational
MHAs	*	*	
Nodes	*		*
Structural Links	*	*	
Clusters		*	
SHEP			*
Menu (figures)		*	*
Menu (text)		*	*
Toolbar		*	
Results Box		*	
Guided Tours	*	*	

Table 6-1 The Design model primitives.

6.2.2.1 Usability criteria.

The usability criteria used in this research for an industrial application are similar to those suggested by Garzotto [Garzotto 97], these are:

- **Retrievability:** How easily can a user find the relevant information? This is commonly called accessibility, yet the term can be confused with the access control in the industrial environment, hence the change of name.
- **Orientation:** The ability of the user to know their navigational position, the information context and the ability to return to a position if required.
- **Reuse:** the design and authoring methodology encourages reuse. However, inappropriate reuse, i.e. by not reusing enough (or too much) information to make sense in the new context, can cause the user to become disorientated
- **Intuitive.** The system will allow the user to grasp the meaning and purpose of the information, dialogue box, window, etc that is being presented.
- **Consistency.** Conceptually similar elements are treated in a similar fashion, while conceptually different elements are treated differently.
- **Accessibility.** How accessible with/without the correct permissions is the information?

6.2.2.2 Defining Evaluation Tasks.

The task definition can be divided into two sections, those for the industrial expert reviewers and those for the general users of the system. The expert reviewer tasks (ETs) use the terminology of the model and are quite general in their description. However the user tasks (UTs) use terminology applicable to the users, and the tasks are more specific in their description. The defining of the tasks also provides uniformity in the evaluation process, especially when different evaluators are involved. Hence, the evaluation process will depend more on the procedure used and less on the evaluator's ability. In addition, the task description will identify critical areas to be evaluated and the appropriate usability criteria for evaluation. The full ETs and UTs task definitions are given in chapter 7 and chapter 7 respectively.

As suggest by Garzotto et al [Garzotto 97] the abstract tasks can be defined using the following headings:

- **Title of Task:** - General heading.
- **Activity Description:** - What the user is required to do.
- **Design Criteria:** - The primitives that are under evaluation.
- **Usability Criteria:** - Those usability criteria that are applicable to the task.
- **Additional Comments.** Here the designer of the evaluation comments, on the rational behind evaluating the task.

6.2.3 Interviews and questionnaires.

In this research, both flexible interviews and questionnaires were used as an effective method of gathering and analysing qualitative data, that is, the users' opinions. The questionnaires were used to find the subjective opinion of the users in the industrial environment. The questions and answers were arranged so that answering the questions by putting a cross all the way down one of the columns would produce a score of zero. The users were forced to make a choice because there was no neutral answer. A full list of the questions used is given in Appendix D.

The questionnaires were designed to measure the scale of: Impression, Command, Effectiveness, Learnability, Aidability, Navigability and Comprehension, and the terms are defined in Table 6-2.

The first five scales are based on The Software Usability Measurement Inventory (SUMI) [Kirakowski 93, Hirst 95]. The last two, navigation and comprehension, are added to measure significant areas specific to hypermedia.

Scales	Definitions
Impression	The users feelings or emotions when using the software.
Command	The measure to which the user feels that they are in control.
Effectiveness	The degree to which the user feels that they can complete the task while using the system.
Learnability	The degree to which the user feels that the application is easy to become familiar with.
Aidability	The degree to which the application assists the user to resolve a situation.
Navigability	The degree to which the user can move around the application
Comprehension	The degree to which the user understood the interaction with the application.

Table 6-2 Questionnaire scales and definitions.

6.2.4 Metrics for the Industrial Environment

The method used, in this research, for compiling the metrics used in the evaluation of the industrial hypermedia was the Goal-Question-Metrics [Basili 94]. The Goals for the evaluation were:

- Goal 1:- Improve the operators/maintainers retrievability of the documentation, see Table 6-3 for questions and metrics for Goal 1.
- Goal 2:- Ensure ease of use of the applications by the operators/maintainers, see Table 6-4 for questions and metrics for Goal 2.

Purpose	Improve
Issue	Retrievability
Object	For viewing documents
View Point	Operators/Maintainers
Questions	Metrics
What is the current situation?	Time taken to complete the task. Average time to obtain documents. Number of documents visited.
Is the hypermedia application better?	Time taken to complete the task. Average time to obtain documents. Number of documents visited. Subjective option of user's satisfaction.

Table 6-3 Table of Goal-Question-Metrics for question 1.

Goal 2 Purpose	Easy
Issue	to use
Object	hypermedia application
View Point	Operators/Maintainers
Questions	Metrics
Can the user find the information?	No of successful finds. Did they get lost/ ask for help? Was the information there? Number of type of documents. Number of hot keys used (short cuts). Did they come to a dead end (had to retrace)?
Does the system help the user navigate the information space?	Number of documents visited. Number of successful finds. Number of hot keys used. Number of menus used. Number of links followed. Number and types of links used. Number of clusters followed. Number of times gets lost/asks for help. Subjective option of user satisfaction.

Table 6-4 Table for Goal-Question-Metrics question 2.

6.3 Summary.

This chapter has presented the general requirements of the user interfaces for the industrial environments. Based on the premise that the resources of time and personnel available to conduct the evaluation are limited in the industrial environment, the user evaluation does not naturally lend itself to usability laboratories. Hence, this chapter has described general methods of user evaluation that can be used in the natural environment of the initial end-users, the factory floor. The evaluation methodology is designed to be carried out by personnel from within the industrial environment.

This chapter presents a methodology for user evaluation of an industrial hypermedia application. Due to the constraints of time and availability of personnel, the methodology consists of five short and distinct evaluation processes. These are:

- Contextual review/inquiry of working practices.
- Discounted usability evaluation of application developed for the case study.
- User questionnaires after training.
- Time trials.
- Normal use evaluation.

Chapter 7.

Structured Expert Reviews.

This chapter presents the results of two structured expert reviews.

The first structured expert review concentrated more on the general look and feel of the user interface and the general navigational aids. This is reflected in the choice of expert reviewers, who were from a computer science and HCI background. As a result of this review, research into managing the user interface was undertaken, which is also presented in this chapter.

The second structured expert review concentrated more on the information structure and the application specific information, and used reviewers from the manufacturing environment for which the hypermedia application was written. As a consequence of the second review, an evaluation associated with the input was undertaken, and the results are presented in this chapter.

There is, of course, considerable overlap between interface design, navigational tools, and the way in which the information is presented, therefore the expert-reviewers were free to comment on any aspect of the hypermedia application.

7.1 The First Expert Review: *evaluating a user interface.*

The first of the structured expert reviews used a completed but unevaluated application for a wire packaging line at Pirelli Cables Aberdare, focusing on the use of the hypermedia

system by maintenance and the factory-floor operators [Crowder 96b]. The project used the standard Microcosm interfaces, similar to those proposed for the Supertension Sheathing line. The advantages gained by using this piece of completed work as a test bed were:

- The evaluation could be carried out earlier than would normally be expected.
- The results could be brought forward into the design of the interface for this research.
- To distinguish between problems relating to the microcosm interfaces and those for a potential user in the industrial environment.
- The experience gained would aid subsequent evaluations.

The general procedure for conducting a structured expert review is to present the expert reviewers with a set of scenarios which they are to carry out in turn. The expert reviewers are then encourage to 'think aloud'. These comments are then recorded for analysis later.

The 'experts' for this phase of the evaluation all had a computer science and HCI background. There were chosen primarily for their expertise in hypermedia. Dr David Lowe, is an internationally recognised expert in the field of Hypermedia, and has published widely on the subject. Dr Steve Rake, after a career with IBM, working on many large computer projects, was a consultant specialising in the use of hypermedia in education. Dr Emilia Mendes, specialised in the design and evaluation of adaptive hypermedia. Mark Weal has been researching the application of hypermedia in digital libraries for over seven years, his specialisation is open interfaces.

The scenarios were chosen to ensure that the reviewers would visit the different user interfaces of the system. The reviewers were asked to look and comment on the flow of information from screen to screen and on each screen to evaluate the HCI. The reporting of any situation encountered, that is, any limitation, possible confusion or shortcoming in the user interface of the system and ideas for improvement were written down for analysis and discussion later. While the reporting system used can be classified as 'unstructured reporting', a predefined form was used to record observations. The form clearly stated the number and title of the scenario to be undertaken. To ensure the rest of the group was aware of what was going on, a 'think aloud' approach was encouraged. In addition, to ensure that good aspects of the design are brought forward into future projects, reviewers

were asked to comment on the positive aspects, and not just the negative aspects of the HCI design.

It was originally intended that the experts would write down their observations, but it was quickly realised that this would not be practical if ideas were to flow freely. Wharton et-al [Wharton 92] point out that they had similar problems, as their reviewers would often get into discussions and forget to write items down. They also suggest using a person to oversee the sessions and ensure that the focus of the discussions is kept on track. However, when the observer is part of the development team, the observer should have minimal involvement in the discussion, except to ensure that ideas flow and the discussion remains on track, so as not to bias the reviewers' comments.

There are several alternatives to solve this problem of ensuring that the comments are noted. These are:

- The use of video will ensure that all the information is captured, that is both the comments and the screen display. However, this approach is only really acceptable in an office environment with plenty of room or in a usability laboratory.
- Sound recording is another approach that will ensure that the comments are noted. However, the observer will need to ensure that the position of the reviewers in the information space is noted.
- An observer with shorthand skills could be used during the evaluation process that takes place on the factory floor, especially where the use of video cameras may be awkward to position and sound recording may be difficult.

This process overcame some of the problems found by Rowley and Rhodes [Rowley 92], who could not get the bulk of the evaluation completed in the time available (90 minutes) as the sessions took longer than planned. However, they were using a cognitive walkthrough approach and this research used scenarios. Walkthroughs involve carefully designed tasks normally taken from the system specification [Preece 94] telling the reviewers exactly what to do, in a step by step approach. Karat et-al [Karat 92] found that their groups also favoured scenarios over self-guided exploration in identifying usability problems.

7.1.1 Results From the First Structured Expert Review.

Appendix E gives the detailed result of the structured expert evaluation using the discounted usability method to evaluate the user interface used in the research [Wills 97].

The nine essential principles suggested by Nielsen, see Chapter 6, give a framework for good human-computer interaction. Since these general principles were first put forward, there has been a rapid growth in graphical user interfaces (GUI). Nielsen's original work was on text based user interfaces. While style guides for general purpose GUIs exist, this research evaluates the specific application of the Microcosm industrial user interface. Some of the points raised by the expert reviewers were unique to the application, and would have been fed back to the original design team had the project not ceased. Others were relating to aspects of the standard microcosm interface, that could only be altered by the microcosm system developers. The remainder can be distilled into general principles, these can be grouped under and amplifying Nielsen's nine principles, making them applicable to the design of any industrial hypermedia interfaces. The results are detailed below, Nielsen's principles are shown in bold, while the bullet points present the general principles distilled from the evaluation:

Use simple and natural dialogue.

- Use only descriptive titles in video, pictures and text boxes. Do not use technical terms that have no relevance to the user.

Speak the user's language.

- Computing and hypermedia terms must not be used in window titles and buttons, as they have no relevance to the operators and maintainers of the plant (especially the operators).
- Careful choice of icons is required. Icons that are used in a Windows based computer systems may not necessarily be easily interpreted by the factory-floor users. Therefore, icons that relate to the industrial application should be used.

Minimise user memory load.

- The user should be able to retain the results of a search, and step through the resultant list. Ensure that the order of the resultant list helps the user, by ranking the results.

- When the operator is required to carry out a number of tasks, a method of recording the tasks that have been completed needs to be incorporated.
- A notepad of some sort is required for the users to make their own notes.

Be consistent.

- There is a need for good screen management. Any screen management must take into account the differing abilities of the users.
- On all toolbars and menus, there should be a distinction between the operators' and maintainers' requirements. In addition, the options should not appear if the user is not able to select those options.
- The colour and style of active/inactive buttons, window borders etc, needs to be predefined before the application is built.

Provide feedback.

- By using clearly marked help facilities, pop-up menus, etc., which are applicable to the application and user.
- Toolbars and menu options that are available only after the user has selected another menu or toolbar option should be greyed out.
- In the case of a button being 'greyed out', the text description should still be displayed on the tool bar or as a pop-up menu.

Provide Clearly Marked exits.

- The user should be able to return to a 'start' screen on completion of a task, without having to manually shut all the active processes down.

Provide shortcuts.

- The number of screen shots of the machine that a user is required to step through before they arrive at the information needs to remain low. Reducing the number of screen shots will also reduce the number of short cuts the author needs to provide. Short cuts are helpful, but a preferred alternative is an application that is better designed.

Provide good error messages.

- The error messages should be linked to a help file. For example the error message 'no link found', does not help the user.

Prevent errors.

- An indication that a selectable mode is active should be clearly displayed to the user.
- When the cursor is not over a button, any previously selected help or pop-up menus should be removed and the information on a status bar should display at least a default message.

7.1.2 Comments on the Results

An area that is particularly applicable to hypermedia and not covered above is that of navigation through the resource base. Therefore, another principle needs to be added and that is '**Provide Navigational Aids**'.

While navigating a large information space, it is quite easy to get lost in hyperspace, even with a good memory. Sellen and Nicol [Sellen 90] explained that the users make mental maps to help them navigate. Therefore, the system should make these maps explicit. They also point out that the maps will take differing forms depending on the hypermedia application. Sellen and Nicol called this 'reducing the memory load', which is one of Nielsen's principles. In both Nielsen, and Sellen and Nicol, navigation is only a minor aspect of the user interface. However, in hypermedia it becomes a major principle. Therefore, reducing the memory load is not sufficient. The system must provide the user with utilities to navigate the information space without getting lost. Hence, any evaluation of a large hypermedia system needs to explicitly assess the level to which the system provides navigational aid, in order to reduce the possibility of getting lost in hyperspace.

The pictorial representation of a process line gave an effective gateway to the information resource database. The three-dimensional model used took a significant time to produce. However, any number of screen shots from different angles are easily produced from a single model. These images are then overlaid with links, as with any digitised photograph or picture. Crowder et al [Crowder 95b] found that users preferred the idealised 3D model of the line compared to an actual photograph of the machines for the interface.

The toolbar approach was found to be a considerable improvement over the basic Microcosm user interface. The toolbar enables ease of navigation by providing short cuts to the underlying information resource database. A significant number of comments from

the reviewers centred around the fact that the toolbar and menus did not distinguish between users. This distinction is necessary so not to confuse operators with options they could not use (even if 'greyed out').

In summary, a number of observations were made during the evaluation, the majority of which dealt with improvements to the user interface. However, the evaluation also showed the use of a toolbar to be an effective method of providing short cut keys. It also showed that the pictorial representation of the production line provided an effective gateway to the underlying information resource.

7.1.3 Comments on the procedures used.

The first group of expert reviewers completed the first three scenarios only, taking one and a half hours, while the second group completed the five scenarios in just over two hours. During this time, the comments of the expert reviewers were noted.

The length of time spent on each scenario varied, with the greatest time spent on the first scenario and the least time spent on the last scenario. This was in part because the points raised in the first scenario were often fundamental principles that applied to the remaining scenarios. The time spent also varied in part, due to the tiredness of the reviewers.

Therefore, either the reviewers should take short breaks during the evaluation process or the time has to be limited to two hours. The scenarios allowed the reviewers to converse more freely and suggest possible design solutions. Careful thought to the scenarios and allowing time for the groups to discuss the user interface layouts ensured that the scenarios were completed in a reasonable time.

7.2 Industrial User Interfaces.

The major advantage with hypermedia is the ability to navigate freely through the information resource database. The comments made during the first review suggested that if the user is to be able to effectively comprehend or act on the information it is essential that the screen real estate be managed effectively. Screen management is concerned with how information is presented to the user on the screen and the tools that enable them to manipulate this information using the interface provided.

The industrial environment brings together users with different and varying computer skills, all of whom need to be supported. Most of the information required by the operator in setting up a machine will involve the use of text, photographs, diagrams, tables, etc. The Microcosm RTF viewer allows the user to view text and embedded graphics. This ensures that sketches that appear in the original paper document appear in the correct place within a hypermedia-authored document. This is of benefit where there is a short piece of text referring to an embedded graphic.

However, the information normally used within an industrial or technical environment, for example manuals, work-packages, instruction-sheets, etc., has text that will quite often refer to a diagram on another page (often several pages away). This can lead to errors while scrolling the pages looking for the diagram. This is similar to the problems experienced in a paper based system, when the user is required to cross-reference information on different pages. In addition, in an industrial hypermedia application, the text will not only refer to another page, but may also refer to information stored in different forms of media. It is therefore essential to be able to display the text next to the information it references.

Many industrial interfaces try to provide a common look and feel for the user interfaces by providing the same user interface for all applications and user groups. What is actually required is an appropriate interface for the task, that has a common look and feel yet allows the different group of users, with different abilities access to the appropriate information.

7.2.1 Screen Management for an Industrial Environment.

As Microcosm has a modular architecture and runs under the Microsoft Windows environment, a number of processes can have interfaces (document viewer, a toolbar, or a dialogue box) on the screen at the same time. The interfaces (processes) all act independently of each other in terms of screen management and can therefore be made to overlap or obscure one another. This may cause problems with inexperienced users. Similarly, inexperienced users may have problems with basic screen management such as inadvertently moving windows off the screen, inability to restore a minimised window, etc. Hence, inexperienced users can soon clutter the screen, losing track of where they are going, or worse still, moves the document off the viewing area never to be seen again.

Hence, a common method used to overcome these problems is to provide a fixed window layout.

The advantage of fixed window layout in hypermedia systems is that it ensures that the most appropriate window layout for the information is seen, at least in the first instance. It allows the text and engineering drawings or video to be placed in pre-defined areas of the screen. Within the factory environment, the need for a fixed window layout is most likely to occur with new operators, accessing information in regard to set-up tasks and faults encountered.

However, in a fixed windows environment, experienced Windows users are no longer free to position and size the window, as they so desire. Hence, they lose the flexibility of having complete control of their working environment. A case in point is during fault finding, where multiple windows are often preferable.

A new solution for tackling the problems created by having users with differing abilities has been designed and implemented by Hall et al [Hall 97]. The architecture, which promotes the disclosure of state information by the individual processes and allows screen management processes to modify the state of the interface components, has been named SHEP (Screen Handler Enabling Process). The implementation of SHEP comes from the requirement to implement the findings from the evaluation described above and the HiDES project [Hall 91]. SHEP was used in the case study application, see chapter 5, to control the layout of the toolbar, manuals and dialogue boxes.

The SHEP solution gives the developers of hypermedia applications flexibility when creating interfaces for users of different and varying ability when using microcosm. The developers no longer need to target the interface at a specific user group at the exclusion of other users.

The SHEP solution allows the designers of industrial hypermedia applications to provide:

- A rigid framework to support novice users, yet at the same time allow more experienced users to turn off parts of the automatic screen management system, in order to provide a more flexible environment, see Figure 7-1. The author will have control of the viewers on the desktop and not just inside a window.

- A system that can be configured to reflect the different user groups. Different tool bars can be used to support the different user categories or different task functions. Similarly, the menu bars associated with the viewers can be designed separately to reflect the different user requirements. These customised menu bars are ‘attached’ to the viewer by the Shepherds in the SHEP system.
- The SHEP architecture allows the developers to provide a common look and feel to the user interface, without the need to provide exactly the same interface.

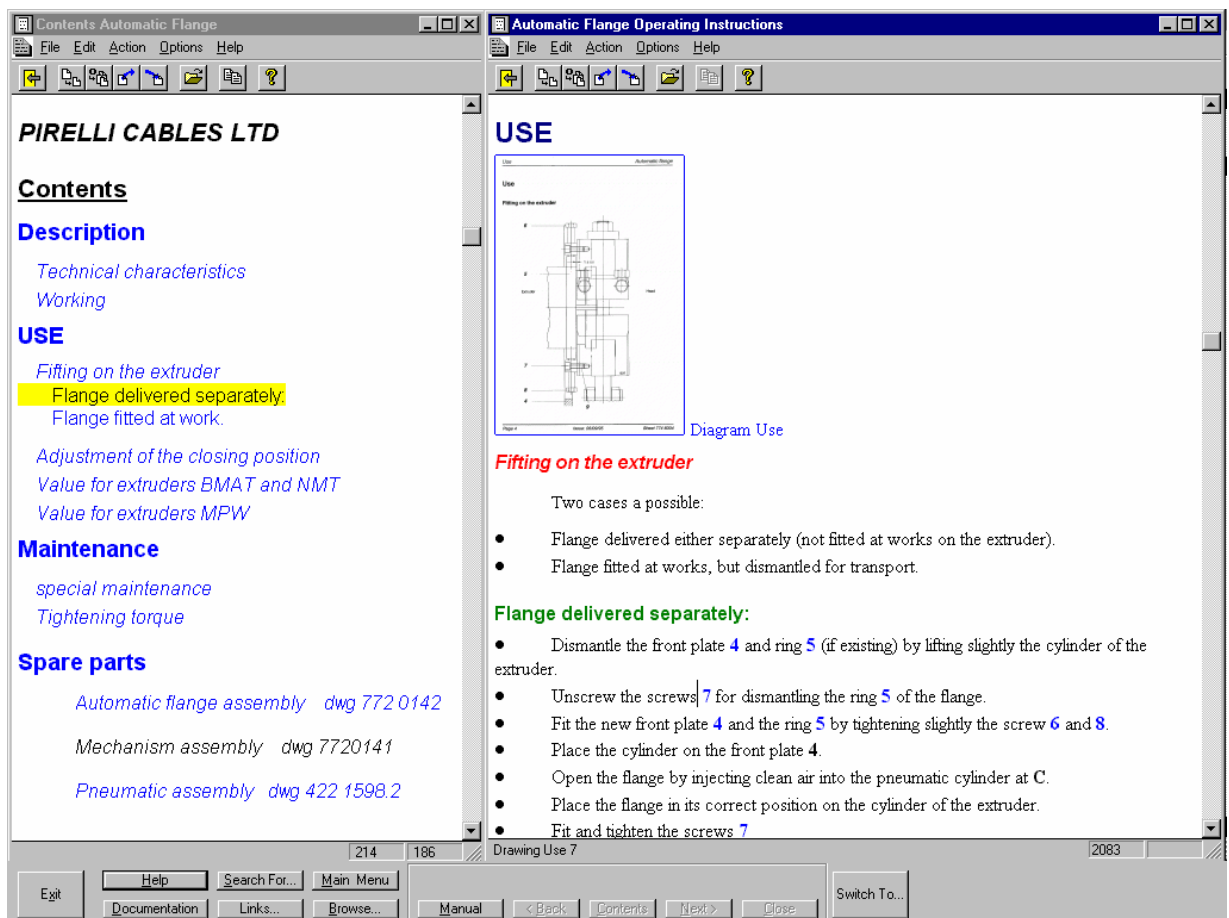


Figure 7-1 The layout of a SHEP controlled manual for the shop-floor operators.

When viewing a large or densely populated engineering drawing, a user can become disoriented as they zoom into the drawing, that is, they do not know where they are in terms of the overall drawing. In addition, objects in an engineering drawing often belong to a family of items, for example, a number of 3-phase switches may have different ratings, but come under the generic name of 3-phase switches. Therefore, it would be advantageous for

the author to be able to make links onto the generic name of that item, or its specific name or any of its attributes.

A new DXF viewer to solve some of these problems has been produced [Price 98]. The authors' contribution was in jointly setting the requirements of the viewer and advising in its development. The result was a DXF viewer that will enable links to be created on all the names and attributes of a block. In addition, the new viewer uses a 'Birds Eye' view of the drawing. This allows the user to keep track of his or her position within the overall drawing when using the zoom feature.

7.3 The Second Expert Review, *evaluating the application*.

The second of the structured expert reviews was conducted at Pirelli Cables Eastleigh and used the application described in chapter 5. The industrial expert reviews were all from the management team of the Supertension line. In the evaluation, the management team was mainly there to review the information structure and the content of the specific information. However, general comments on the look and feel of the pilot application were encouraged.

7.3.1 *The Expert Reviewers*

The expert reviewers were all from the management team of the Supertension cabling line.

- ER 1 Manufacturing Manager.
- ER 2 Maintenance Engineer.
- ER 3 Principal Process Engineer.
- ER 4 Process owner.

The expert reviewers were chosen because of their experience in the field of manufacturing cables and not computer science. The age range of the experts was from 30 years to 55 years, and they had worked in the industry from 12 to 35 years. All of the reviewers use personal computers daily and use e-mail in the course of their work. In response to questions, see Figure 7-2, on their experience of using computer packages such as word processing, spreadsheets and presentation packages:

- Only one of the reviewers classified himself as an experienced user. He was also the only person to have written macros.
- The other three reviewers classified themselves as either novice or intermediate users.
- None of the reviewers classified themselves as expert users.

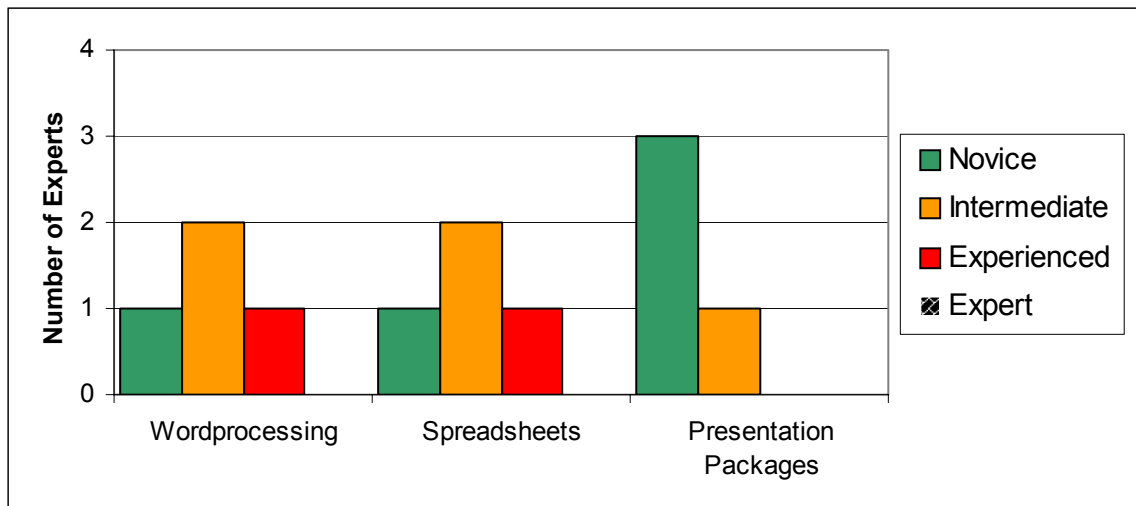


Figure 7-2 Expert Reviewers self assessment of experience with software packages.

7.3.2 The procedure.

All four expert reviewers attended a training session on the use of hypermedia. The structured expert reviews were carried out over two sessions. The first was with ER 4, the second with ER 2 and ER 3, see Table 7-1. The expert review was given four scenarios recorded as expert tasks, ET 1 to 4, shown in Table 7-2. The experts were asked to make comments whilst carrying out the scenarios, in accordance with the principles set out in Chapter 6. The observer took notes and occasionally prompted the reviewer for comments. The activity descriptions for the scenarios were slightly modified between the first and second group of reviewers. That is, the manual upon which the reviews were asked to comment was exchanged between tasks 2 and 4. This did not affect the design or usability criteria under examination. The reasons for the slight change, being that not all of the recommendations suggested from the first session had been implemented in time for the second session, that is the diagrams were not included. Hence, to encourage comments on the different methods used to represent diagrams within the manuals, the reviewers were asked to examine a different set of manuals. The length of time taken to carry out the first review was 46 minutes. This was the expected length of time for an expert reviewer working alone. The length of time taken to complete the second session with two expert reviews was just over 60 minutes. The sessions were initially planned to take 90 minutes based on 3-4 expert reviewers. The time allocation of 90 minutes for 3-4 reviewers was based on the experience gained while conducting the first of the structured expert reviews

reported in section 7.1. The more reviewers in a session naturally generates more discussion per scenario and hence takes longer.

	ER 1 Manufacturing Manager	ER 2 Maintenance Engineer	ER 3 Principal Process Engineer	ER 4 Process owner
Training	*	*	*	*
Session 1				*
Session 2		*	*	
Input device	*		*	*

Table 7-1 A summary of which sessions the expert reviewers attended.

Scenario	Activity Description	Design Criteria:	Usability Criteria	Additional Comments
ET 1 General Introduction	Switch on and log into the system. Use General help to find information on operator overview.	Structural Links, Clusters, Menu (text), Toolbar	Retrievability Orientation, Intuitive, Accessibility	The experts are to examine from switch on if the navigation of the system is intuitive
ET 2 Examining the presentation of a Manual	From the main menu, under the main heading of on-line manual select the Eurotherm Manual. Navigate around the manual check drawings	MHA, Nodes, Structural links, SHEP.	Retrievability Orientation, Intuitive, Consistency.	The Experts will be using SHEP and examining text and diagrams
ET3 Navigation using the guided tour and history Box.	From Select-a-Document window select the guided tour. Follow the guided tour. Check the links out of the tour. Retrace some of your steps using the history list. Return back to the main menu	MHAs, Nodes, Structural Links, SHEP, Menu (text), Results Box, Guided Tours.	Orientation, Intuitive, Consistency.	The task is designed to test the system as the users move through and out of a predefined tour. Can they also revisit items of interest later?
ET4 Navigate information that has been reused.	From the main menu, select the line diagram and either of the caterpullers. Examine the documentation for that machine.	MHAs, Nodes, Structural Links, SHEP, Menu (figures) Menu (text), Guided Tours.	Retrievability Orientation: Reuse: Intuitive. Consistency Accessibility.	The MHA contains information that is reused. That is there are documents common to both caterpullers.

Table 7-2 A list of the Expert Tasks used in the evaluation.

The sound recording acts as an aide-mémoire for the observer in writing the report only, therefore all sound recordings are erased once the report is completed. The sound recording of the comments proved useful especially when there was only one reviewer. The usefulness of the sound recordings was in part due to the observer needing to encourage the reviewer to think aloud. If unused to this, it can be intimidating. In addition, the observer found it difficult to both engage the reviewer and write detailed notes, especially once the evaluation neared the end of the session when the expert reviewer's suggestions flowed more easily. Hence, listening to the sound recordings helped in compiling the evaluation results.

7.3.3 Results

The observations made by the reviewer were grouped into three categories, namely: -

- Content: - these observations were to do with the actual content of the information, i.e. missing links or nodes.
- Presentation:- these observation were to do with presentation and navigation of the information
- System: - these observations were to do with how the user interacted with the application software.

In categorising the observations, some of the observations can clearly be placed in a number of different categories. Hence, the observations are placed in the category that best represents the main point of the observation. A full list of the comments is available in Appendix F. However, the observations that most concerned the expert reviewers can be summarised as follows:

Content

- There were a number of occurrences where the system showed links to a number of bitmaps and documents, yet the reviewer was unable to follow them. While the error message was explicit 'no document found', the system still opened a blank viewer, which could not be closed until the reviewer exited the system.
- The other observations were requests to add additional links.

Presentation.

- Displaying of a bitmap from the thumbnail sketch was cumbersome, that is, the bitmap was wider and deeper than the screen. This will confuse the operator, as it is difficult to resize the window, as it is too large.
- There were a couple of observations regarding the use of the bitmap viewer. The first was concerned with the initial start-up position. This can be fixed by setting the default position. The other was to do with losing the tool bar when resizing an application window.
- The table and figures that are embedded into the document were not completely visible. That is, only part of the table or figure could be seen, as no horizontal scroll bars were available on the viewer. This was exacerbated by the fact that the screen layout was under SHEP control. Hence, the Shepherd would not allow the window to be resized.
- The experts expressed concern about the ability of the system to display a large drawing (A0) with a 17-inch monitor. A further complication was that the users often needed to view other information alongside the drawing.
- The other observations were to do with the presentation of the material using SHEP, or the size of the documentation. For example how to control the page turn so that drawings represented by thumbnails are included.

System.

- The main concerns were with the logging process. The reviewers felt it should be as simple as possible and without the user needing to know how Microsoft Windows operates. For example, one request was that the designers change the system, to enable the reviewer to log in once (into Windows) and the system would then log the reviewer into FIRM, and auto-start the application.
- A few of the observations referred to functionality in terms of buttons to the toolbar. For example, to clear the screen and return to start, to jump back to a document the user marked as interesting, etc.
- The information is required at the point of use.
- The Glide pad as an input device was too sensitive and hence awkward to use.

7.3.4 Comments on the Results.

The review highlighted a number of areas that required changes to the underlying authoring environment and navigational aids and hence identified the software tools still required before the user trial could take place.

However, several of the observations that the reviewers thought important, could not be rectified, as they would involve changes to the source code of Microcosm or Windows NT. For example, when one of the reviewers zoomed into a diagram using the bitmap viewer, the window would resize itself. In doing so, the task bar was not fully displayed, therefore only the first few icons could be seen, and used, i.e. tool bar does not wrap. This is a function of the bitmap viewer and is common to many Windows applications. Similarly the problem where the tables and figures that are embedded into the text document could not be read, because the viewer is made smaller due to no horizontal scrollbars, is a 'bug' or design flaw of the Microcosm RTF viewer.

The guided tours in the pilot application were used to maintain the original structure of the manuals and procedures. Guided tours were not effectively supported in the administrative layer. However, the information from the guided tours was used within the FIRM authoring environment to enable the user to step through the original structure as thought, they were pages in a manual. This was an improvement over the Microcosm guided tour, as it allows the user to step back as well as forward and the user can jump into any part of the tour. Predefined tours are part of the wider issue of how the user navigates a large industrial application and associates nodes of information, again braking the confines of the paper paradigm.

Each of the scenarios was designed to evaluate aspects of the design and usability criteria. As stated earlier the expert reviewers were not computer scientists or usability experts. Hence, the language used to describe observations could not be mapped directly to the criteria under evaluation. However, the purpose of the review was to assess the suitability of the system for the factory environment and in particular the factory-floor. Hence, the observations made were focused purely from the user's point of view. However, by examining the observation closely, the lack of criticism showed that much of the system was transparent to the users.

There were also some positive comments. For example the '*close button*' on the toolbar to close all the pages of the manual pages was a useful button and the thumb nail sketch approach for ensuring large diagrams do not interfere with the reading text worked well.

7.3.5 Comments on procedure.

All comments and observations were accurately and factually recorded [Wills 98b]. However, what was not initially recorded was the weighting given to the observation made by the expert reviewer. Hence, time could have been spent on correcting some of the less crucial issues, that is the observations that are the easiest to fix or at least the more interesting to the developers. There is always a danger with classification of observations using terms such as, major and minor, or important and not important, that the observations with the lower rating are ignored out of hand. It is however, always the choice of the designer/project manager as to which observation is allocated resources.

During the examination of the evaluation results, it is essential that topics discussed by the reviewers in passing or between scenarios, that are of a general nature and cannot be attributed to any particular scenario, are given full consideration. For example, the comments made about the usability of the touch pad and the drawing issues. These are much bigger issues than the usability of certain scenarios. What at first might appear to be a minor, or a not important, observation can have wider significance if repeated by different groups of reviewers in different sessions. Hence, the observer or evaluation team needs to be aware of trends and the significance of comments made by expert reviewers. Therefore, it is essential that the observers record all comments, even those that do not appear to be important. This requirement is in addition to the weighting of observations made by the expert reviewers. The essential lessons learnt from this review were:

- Classification or Weighting given to the observation made. Preferably, this should be carried out by the expert reviewers at the end of the session.
- Ensure that full consideration be given to topics raised by the reviewers that are of a general nature, yet are repeated in subsequent scenarios or by different groups of reviewers.

An additional advantage of carrying out these types of reviews is that they allow the user to get involved in the development process. This was especially relevant in the case of Pirelli Cables, where the original senior manager who endorsed the project were promoted and

moved to a different site. Hence, the review proved to be a successful mechanism in which the line management could be involved in the development and begin to become owners of the project concepts.

7.4 Evaluation of the Input Device.

It was Pirelli's policy that all computers on the factory-floor be housed in a purpose built enclosure. As space on the tray holding the keyboard was limited, and a conventional desktop mouse would soon become unusable due to the ingress of dirt, grease bitumen etc, a touch sensitive pad (called a Glide pad) was initially chosen for the case study system. Three of the expert reviewers found the touch pad cumbersome to use. This could have been attributed to a lack of practice. However, the experts were concerned that the users on the factory floor would have similar difficulties using the touch pad. Hence, an alternative input device was sort. The options immediately available were:

- A conventional mouse (Figure 7-3).
- The Glide pad, built into the keyboard (Figure 7-4).
- An Electronic Pen and Pad (Figure 7-5).
- Touchscreen add-on manufactured by Carroll Touch (Figure 7-6).
- TrackMan Marble FX supplied by Logitech (Figure 7-7).



Figure 7-3 Mouse



Figure 7-4 Keyboard with glidepad



Figure 7-5 Pen and Pad

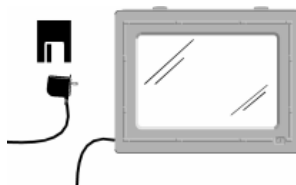


Figure 7-6 Add-on Touchscreen



Figure 7-7 TrakMan Marble FX

The conventional mouse was used as a base-line device, as all the reviewers had experience of using the device. Each of the reviewers attending this evaluation session (ER1, ER3, and ER4) tried to use the devices to move the cursor, follow links and select text. The reviewers were then asked to fill in a questionnaire consisting of the questions, shown in Table 7-3, for each device. A score was then given to each of the answers as shown in Table 7-3. The questions were asked in such a way that the reviewer had to make a choice. In addition, the questions were structured so that not all the favourable choices were in the extreme right or left boxes. The results of the scores given by the reviewers are shown in Table 7-4.

How did the device feel to use	Very Awkward (1)	Awkward (2)	Natural (3)	Very Natural (4)
Using the device to move the cursor to an area on the screen was:	Very Easy (4)	Easy (3)	Difficult (2)	Very Difficult (1)
How well were you able to select a link	Very Easily(4)	With Ease (3)	With some Difficulty (2)	Very Difficult (1)
How difficult was it to select a piece of text	Very Difficult (1)	Sometimes Difficult (2)	Not Difficult (3)	Easily (4)
How quickly were you able to use the device effectively	Straight away (4)	Requires some practice (3)	Requires a Lot of Practice. (2)	Never able to use it probably. (1)

Table 7-3 Question asked to review the input devices, score in brackets.

Question	TrackMan	Mouse	Glide Pad	Touch Screen	Pen and Pad
The feel of the device to use.	9	10	8	6	5
Ability to move the cursor:	10	12	9	10	7
Ability to select a link	10	10	7	7	6
Ability to select a piece of text	11	9	9	7	6
Ability to use the device effectively	11	10	10	7	6
Total	51	51	43	37	30

Table 7-4 Results of answers to the questionnaire.

The reviewers were also asked to rate the devices in accordance with their preference of device for use on a factory-floor system. The first choice of all the reviewers was the TrackMan.

The touch screen was rejected, due to having similar problems to the glide pad. In both cases, if the user accidentally touches the screen with any other part of the hand a false reading takes place, i.e. the system highlighted unwanted pieces of text or jumped to a different location other than where the user was trying to move the cursor. In addition, the touch screen suffered generally from parallax error and was out of alignment near the edges of the screen. These problems may have been compounded by the use of an add-on touch screen rather than a built in touch screen. One of the reviewers also expressed concern with the user's arm getting tired from using the touch screen. This is a known problem with touch screens [Preece 94].

7.5 Summary of the points found in the Reviews.

The first structured expert review, based on the Aberdare application, provided guidelines for future industrial Microcosm interfaces. The second structured expert review used the application, described in chapter 5, and used experts from the industrial environment rather than HCI specialists. Hence, the observation made concentrated more on the general look and feel of the application and on the content of the information.

While the evaluation found a number of problems, it also presented a number of principles by which to design and develop industrial strength hypermedia. The lessons learnt from the evaluation method can be applied to other industrial hypermedia research, such as the FIRM project, both in the user interface design and in the evaluation process. These can be summarised in to two sections procedural and results

Procedural

- While the discounted usability evaluation method will not find all the problems with a user interface, it has proven a quick and cost effective solution in the first instance. In particular Nielsen's nine principles provided a sound basis for the evaluation of general user interfaces.
- The evaluation showed that for a hypermedia application an extra principle of 'Provide Navigational Aids' is required to explicitly examine this feature of hypermedia applications.

- Careful thought to the type and number of scenarios in a session should be given. This ensures that ideas flow freely and the session is completed in a reasonable time without the reviewers requiring to take breaks, ideally 90 minutes.
- When the observer is part of the development team, the observer should have minimal involvement in the discussion, except to ensure that ideas flow and the discussion remains on track, so as not to bias the reviewers comments.
- The sound recording acts as an effective *aide-mémoire* for the observer.
- An analysis of the results must include a weighting categorisation of the observation and not just a factual recording. In addition, close attention should be given to general comments that could not be assigned to a specific scenario and comments although seemingly insignificant, but when repeated several times by the reviewer, increase their importance

There are several additional advantages from carrying out the structured expert review prior to the timed user trials, these are:

- With a few reviewers, the majority of the HCI problems are generally identified [Nielson 92]. This is also shown by the lack of problems found in the user trials.
- Using a few experts for only a short period of time reduces the cost of evaluation.

When the expert reviews are from the management team, ownership of the project and application takes place

Results

- The use of the toolbar was shown to be an effective method of providing short cuts.
- The pictorial representation of a process line gave an effective gateway to the information resource database.
- The traditional fixed-page screen format, as the only method of displaying the information, is too restrictive for a hypermedia user interface on the factory floor. SHEP will provide some of the solutions for dealing with the flexible environment required by an industrial user interface.
- For the specific application, the TrackMan input device was the choice of all the reviewers.

Chapter 8. User Evaluation.

It is important when introducing a new system into a manufacturing area, to gain the support of the management team. This was achieved by involving the management team in the contextual reviews, expert reviews and usability discussions over a two-year period. The next phase, and probably the most crucial, in the introduction of the new system, was to produce the same confidence in personnel from the factory floor. This was achieved through a programme of training, during which the purpose and benefits to the organisation and themselves, of the hypermedia application were explained. In addition, the users were encouraged to suggest documents for inclusion, and any other information they would find useful.

Two sets of time trials were undertaken. The user group consisted of personnel from the maintenance section. The first set of timed trials was undertaken approximately six months after training and the second trial six months later. In addition, a much smaller timed trial was conducted using personnel with no experience of the paper-based documentation system. The object of these trials was to evaluate the effectiveness of an open hypermedia system, when used on the factory floor. It does not explicitly evaluate the methodologies used to create the application.

This chapter presents

- The user profile
- The results from the training program and user's initial comments.
- The results and conclusions from both sets of the time trials.

8.1 Users Training and Background.

The user training consisted of four one-hour sessions:

- Basic computer interaction, for those who had not used Windows before.
- Introduction and background to the project.
- Introduction to Microcosm.
- Navigating the pilot system.

At the start of the first training program each of the trainees filled in a self-assessment questionnaire similar to the ones given to the expert reviewers. There were twenty-one users trained at Pirelli: four members of staff; six factory floor operators and eleven maintenance technicians (including one senior apprentice). Fifteen of the twenty-one users returned questionnaires. In addition, to ensure that the methodologies are applicable to other industries, nine employees from Ford Motor Company, at Swaythling, were trained to use the system, and eight of whom personnel returned questionnaires.

All management staff use computers in the course of their daily work, using Windows 95. One of the staff members had written macros for Excel.

The operators do not use personal computers at work and none had a computer at home. Their ages ranged from 26 to 60 years, with an average age of 46 (SD 9.2). However they had all used the user interface with a fixed screen layout display, to enter data into the LCU (line control unit), for setting-up the process line.

In contrast, all the maintenance technicians use computers daily at work, using the Windows 95 operating system. None of the maintainers had programmed computers or written macros, and only three of the maintainers used a computer at home. The average age of the maintainers was 42 (SD 13.5), range 18-60.

The nine Ford employees trained to use the system were two production engineers and seven maintainers. They all use computers during their daily work, with the Windows 95 operating system. All had computers at home and four of the nine had written macros for applications at work. The average age of the maintainers was 34 (SD 8.5), range 18-50.

The two apprentices, used only in a timed trial, were there to demonstrate the effectiveness of the hypermedia system with people not familiar with the paper-based system. Both apprentices were age 18 and while both were familiar with the Windows operating system neither had used the WWW.

8.1.1 Results from the questionnaires, after training.

After training the user groups were given time to use the system on an ad-hoc basis. After a period of approximately a month, all the users were asked to fill in another questionnaire. Figure 8-1 shows the normalised scores for each of the scales defined in chapter 7. Appendix G shows the percentage of personnel who answered the questions positively.

The response to the questionnaires showed that the users had a positive impression of the system. For example, no one agreed with the statement that the system was demanding and not enjoyable (or frustrating/awkward) to use. However only 70% would recommend the system to their colleagues.

Similarly, the users felt in command when using the system and that it was effective in obtaining information. For example, 100% disagreed with the statement that they had no control over the system, and 91% felt that the system responded quickly enough to their selection. Every one found the information they required and 91% said that it was straightforward. However, 22% of users thought that there were too many steps to get to the information.

While 96% of the users found the information to be clearly presented, understandable and consistent, 26% thought that there was too much text displayed at any one time.

Generally the aidability (see chapter 7) of the system was high, with the exception that 26% thought that the system was awkward to use when doing something out of the ordinary. Similarly, 43% of users felt safer keeping to familiar methods for retrieving information. However, 74% of the users felt safe trying different methods and 96% felt that they were sure that they were using the right command.

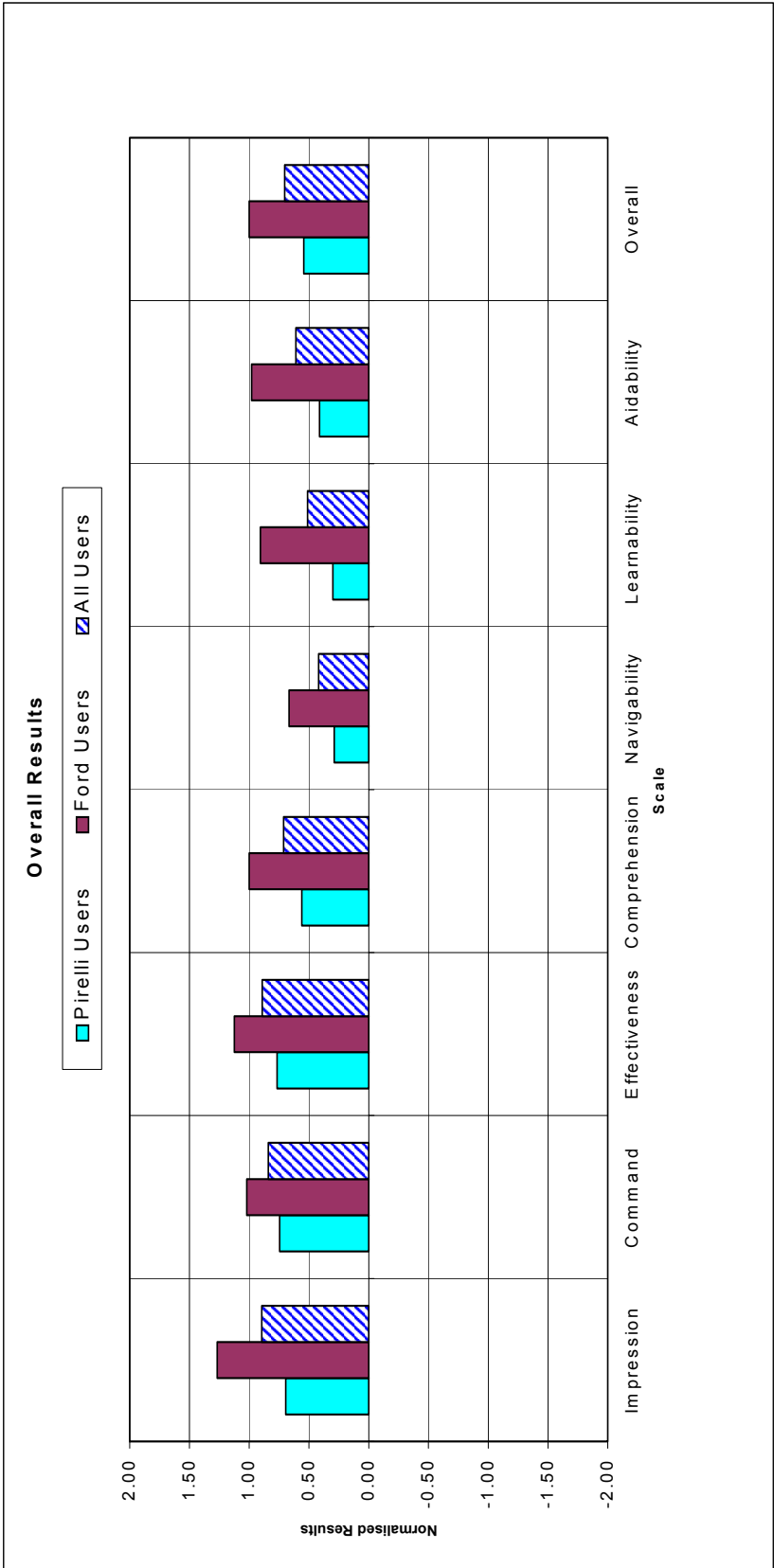


Figure 8-1 User opinions of the system after receiving training.

78% of the users found it easy to move around the information, with 87% finding many different ways to get to the information they needed. However, 43% of users felt that it was easy to become disorientated when using the system.

The scores allocated to each of the scales were normalised and are presented in Figure 8-1. Each score was divided by the number of questions used to measure the scale and the number of users that returned a questionnaire. The possible range of normalised score was -2 to +2.

8.1.2 Comments Raised by the Users during Training.

The operators at Pirelli had been working on the process line since it was installed two and a half years prior to the hypermedia training program. Consequently they had 'grown-up' with the machine and had seen nearly all of the problems before.

During the training on how to use the case study hypermedia application, the operators were encouraged to discuss their opinions and thoughts on using this system on the process line.

The points the users raised were:

1. Their main concern was with delivering the information to the point of use to reduce errors. For example, at the time the operators stood in front of the LCU input terminal, with a laminated copy of the set-up sheet in one hand and typed in the data with the other. This they believed ensured that data could be quickly and correctly entered and easy to check for errors. Hence, they need the information at the point of use.
2. There was concern relating to the amount of information that could be displayed and still be legible. For example, the font size was too small on the tool bars and menus used on the GUIs for some operators. If the operator wore bifocals, the head sometimes needed to be tilted back making it very uncomfortable to read the screen. In addition, the set-up sheet had important information at the bottom of the sheet that needed to be read. However to read the sheet effectively, on the screen, the size was such that the bottom portion of the screen was lost. Therefore, the operator had to remember to scroll down the page, to read this information. The spreadsheet was designed for printing, and when most of the white space was removed, the information could be seen. This highlights, the problem encountered when moving from the printed to electronic media.

The maintainers' experiences at Pirelli of working on the process line were similar to that of the operators. That is, most of them had been working on the process line since it was

commissioned. In addition, most of the faults could be fixed by simply resetting trips or replacing component parts that regularly failed. The maintainer's comments on the documentation were:

1. The maintainers wanted more information to be included. This went beyond what they had in the paper-based system. For example, the documentation told them how to set up the drive unit, but not the actual parameters to be used. Similarly the manual for the Siemens motor refers to a series of motors, but there was no information about which motor was actually used or its operating characteristics (max speed, max torque, max current, etc). The maintainers also requested information on the PLC ladder logic, with a simple help function to remind them of the symbol's meaning.
2. The maintainers wanted to be able to annotate drawings with changes or modifications often called "redlining" in document management systems.
3. The maintainers also wanted the information at the point of use. For example, the filling out of on-line forms where the measurements are taken from the back of the machine. Unless the data could be entered at the point of use, the maintainers would need to record the results on paper then enter the information into the database, in effect carrying out the task twice.
4. The computerised system would allow the maintainers to keep other records more conveniently. For example, the records and forms for TPM, shift diary and hand-over book to inform the other shifts of important information. At the time, they used bits of paper that were "forever getting lost".

What this indicated was that there was a need to change the working practices as well as changing the way the system displayed the information. Hence, discussion took place between the line management and the author on how best to do this before the system went live on the network.

The comments from the Ford group of users were similar to the comments from the maintenance group at Pirelli. The comments were positive. For example, one of the engineers commented that in his experience of trying to locate information during a breakdown situation, the hypermedia system is a vast improvement. The main concern was using the information at the point of use. The other comment was that they would like to

publish to other users, useful or commonly used trails, through the information space. Similar requirements were expressed in the Memoir project [Hill 97].

8.2 User Task Evaluation.

The object of the time trials was to measure the effectiveness and ease of the hypermedia application to locate information, and not the faultfinding ability of the operators. Hence, the tasks were chosen to reflect this, and by measuring only the time taken to locate the information. The matrix and rationale behind the procedures used for these tasks is described in Chapter 7. There were nine maintainers used in the time trial. The measurements obtained from the timed trials are shown in Table 8-1. The user trial was a single factor design [Foster 98], with the single factor being the information resources used (with two variables, electronic and non-electronic), and with repeated measures. The maintainers tasks were divided into mechanical and electrical tasks, see Table 8-2.

	Paper based information	FIRM Information
Measured directly	Time taken to complete the task Number of documents visited Number of successful finds Number of indexes/Contents pages used	Time taken to complete the task Number of documents visited Number and types of links used Number of short cuts used
Observed	Did the user get lost	Did the user get lost
Derived	Average time to obtain documents	Average time to obtain documents

Table 8-1 The measurements obtained from the timed trials.

The trial tasks were confirmed with the line's maintenance engineer, responsible for the line, to ensure that the tasks were well defined enough to allow the maintainer to find the information without being too directive.

The tasks were designed to evaluate the design and usability criteria presented in Chapter 7. The only usability criteria not evaluated was accessibility, as all links were available to all maintainers.

Task	Activity Description	Design Criteria	Comments
Electrical 1:	The tracing heating element, for the bitumen tank is not working for zone two. You are to locate the two Pirelli drawings that show the interconnection for the heating element and the thermocouple for zone 2.	Menu, Nodes MHA, Toolbar	Pirelli specific information, using a drawing list, also using the toolbar to back track.
Electrical 2:	The caterpuller pay-off will not jog forward but will jog backwards. You are to identify the relay responsible and its location in the Caterpuller's DC-Drive Cabinet (Eurotherm).	Menu, Nodes MHA, Toolbar, Information reuse	The information is the same for both caterpullers. Uses links in Bitmaps.
Electrical 3:	No power to the compressed air system. On what terminal rail and on what pins is the supply to the compressed air system?	Menu, Nodes MHA, Toolbar	Uses new DXF viewer
Mechanical 1:	Locate the information on how to assemble the crosshead.	Menu, Nodes MHA, Toolbar	Straight text search.
Mechanical 2:	Locate the information concerning changing the belt on the caterpuller, and the appropriate drawings.	Menu, Nodes MHA, Toolbar, Information reuse	Ability to reference drawings in the text
Mechanical 3:	What is the Nokia's spare part number for the filter on the extruder's feeding pipe assembly and its location in the assembly drawing.	Menu (text, figure) SHEP Nodes MHA, Toolbar	Moving between text, drawing and parts list.

Table 8-2 User Tasks for the time trials.

The order in which the maintainers perform the tasks, and whether they carried out a task with the paper system first (P) or the hypermedia system (H), was randomised to balance out any learning effect, see Table 8-3. The maintainers were numbered based on when they were released by the maintenance engineer to carry out the tasks. There were four electrical maintainers (E) and five mechanical maintainers (M).

Maintainer Number	1	2	3	4	5	6	7	8	9
User	E	M	E	E	M	M	E	M	M
Media to be used First	H	H	P	P	H	P	P	P	H
Order of tasks	2,3,1	3,1,2	1,2,3	1,2,3	2,3,1	2,3,1	3,1,2	1,2,3	1,2,3

Table 8-3 Order of Tasks for Maintainers during the timed trial.

On completion of the tasks, the user filled in a questionnaire. The questionnaire was similar to those used to ascertain user opinion after training, with some additional questions to quantify the users opinion of the two systems, see results Table 8-6. To aid the reader the path through a typical maintainers scenario is described in Appendix I.

8.2.1 Hypotheses to be tested.

The first hypothesis:

H₀: Retrieving information using the hypermedia system is no quicker than using the paper-based system.

H₁: Retrieving information using the hypermedia system is quicker than using the paper based system.

The second hypothesis:

H₀: The hypermedia system is no easier to use than the paper-based system.

H₁: The hypermedia system is easier to use than the paper based system.

To determine if the differences between the paper and hypermedia results are significant an analysis of the variance was used. In this research, the t-test was used to compare the means of variables, as the number of samples was less than 30. The Wilcoxon signed-rank test was used to compare the distributions of two related variables, by considering information about both the sign of the differences and the magnitude of the differences between pairs of variables. Appendix G gives details about the statistical tests used.

8.3 Results from the First Timed Trial.

A summary of the time taken to perform the tasks, the mean time, the standard deviation and the results of a t-test for significance are shown in Table 8-4, with the complete data in Appendix G. A result identified by a single asterisk (*) indicates the results are statistically significant at the 5% level, a double asterisk (**) statistically highly significant at the 1% level, a triple asterisk (***) at the 0.1 level, statistically very highly significant [Chatfield 83].

The difference in the overall scores from the questionnaires, (used to ascertain the users opinion of the hypermedia system, after training and after the time trials) is shown in Figure 8-2. The same scoring system was used for both the training and timed trial questionnaires, presented in section 9.1.1. Table 8-6 shows a summary of the scores for the questions used to compare the usability of the two systems. In Table 8-5 what is meant by the 'user getting lost' is that the observer could see that the user was struggling and hence gave some advice or the user asked where to go next.

Task	Type	Mean Time s (SD)		t-test
Task 1 Electrical	Paper	96.0	(51.0)	P=0.196
	Hypermedia	65.2	(22.0)	
Task 2 Electrical	Paper	234.8	(57.2)	P<0.01 **
	Hypermedia	76.0	(19.5)	
Task 3 Electrical	Paper	199.5	(112.9)	P<0.05 *
	Hypermedia	54.2	(22.4)	
Task 1 Mechanical	Paper	137.4	(14.0)	P<0.05 *
	Hypermedia	31.4	(21.0)	
Task 2 Mechanical	Paper	108.6	(47.5)	P<0.05 *
	Hypermedia	43.6	(3.7)	
Task 3 Mechanical	Paper	123.8	(28.6)	P<0.05 *
	Hypermedia	44.2	(10.1)	
All Tasks	Paper	147.0	(82.8)	P<0.001 ***
	Hypermedia	51.0	(22.7)	

Table 8-4 A summary of the average time to complete the task.

	Number of documents visited		Time (s) spend on locating and studying each document		Number of occasions the user become lost*		Number of short cuts /indexes		Number of links used.
	Paper	Hypermedia	Paper	Hypermedia	Paper	Hypermedia	Paper	Hypermedia	
Electrical Total					7	0	12	37	45
Mean	12.0	5.8	17.7	12.2	0.6	0.0	1.0	3.1	3.8
SD	6.3	1.2	13.0	6.5	0.8	0.0	1.1	1.3	1.2
Median	11.0	6.0	14.8	3.0	0.0	0.0	1.0	3.0	4.0
t-test	P<0.01**		P<0.05*						
Mechanical Total					5	1	24	27	40
Mean	12.8	4.7	10.5	8.5	0.3	0.1	1.60	1.8	2.8
SD	5.8	1	4.3	2.6	0.5	0.3	0.99	0.8	1.0
Median	12.0	5.0	10.9	8.8	0.0	0.0	1.00	2.0	3.0
t-test	P<0.001***		P= 0.21						
All Tasks					12	1	36	64	85
Mean	12.4	5.2	13.7	10.5	0.4	0.0	1.3	2.4	3.2
SD	5.9	1.2	9.7	5.0	0.6	0.2	1.1	1.2	1.2
Median	11.0	5.0	11.9	9.9	0.0	0.0	1.0	2.0	3.0
t-test	P<0.001***		P<0.05*						

Table 8-5 Usability Data, per task, from the first timed trial.

Questions	Paper Based		Hypermedia		Wilcoxon Signed Ranks Test
	Score	Mean (S.D.)	Score	Mean (S.D.)	
I would want to use on a regular basis	-6	-0.7 (1.0)	11	1.1 (0.3)	P<0.001
It was not frustrating to use	-7	-0.8 (1.1)	10	1.2 (0.4)	P<0.001
I found it straightforward to get to the information	-9	-1.0 (0.9)	9	1.0 (0.0)	P<0.001
There are not too many steps required to get to the information I needed	-12	-1.3 (0.5)	9	1.0 (0.0)	P<0.001
It would not get in the way of the task I was undertaking	-8	-0.9 (0.8)	9	1.0 (0.9)	P<0.001
I did not find it difficult to obtain the information I needed.	-5	-0.6 (1.2)	7	0.8 (0.7)	P<0.001
I did not become lost/disorientated when using the computer-based system	-7	-0.8 (1.1)	7	0.8 (0.7)	P<0.001
Total	-54	-6.0 (1.0)	62	6.9 (0.6)	
Normalised	-0.75		0.86		

Table 8-6 A summary of the response to the questions comparing the usability of the systems.

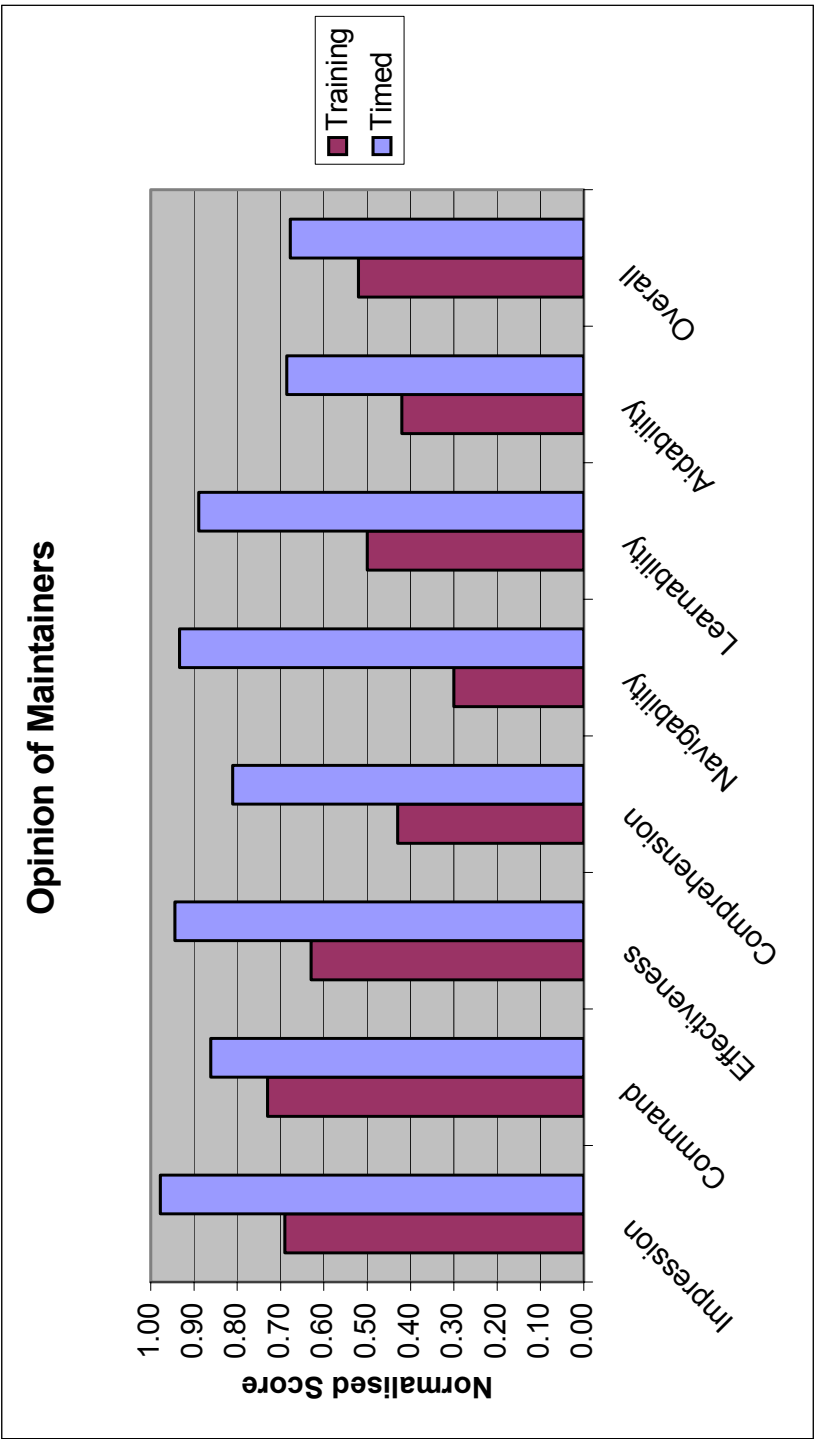


Figure 8-2 Chart of the difference between the scores after training and after the first timed trials.

8.3.1 Comments on time-trial results

Generally, the results show that there is a statistically significant difference between using the current paper-base information system at Pirelli and the case study hypermedia application. That is, the users were not only able to find the information more quickly using the hypermedia system, they had to visit less documents, and got lost less often. In addition, the users, via the additional questions on the questionnaires, showed that they significantly preferred the hypermedia system to the current information system.

From Table 8-4, it can be seen that in each case it took approximately an average of one-third of the time to locate the required information than the paper-based system. Except in task 1, the difference in the time to complete the task between the hypermedia and paper-based systems was statistically significant. However, when analysing the entire group together the time difference is very highly significant. Hence the first null hypothesis can be rejected and the alternative hypothesis is accepted. That is, retrieving information using the hypermedia system is quicker than using the paper based system. The probable reason for task one not being statistically significant was the fact that the drawings for existing equipment within Pirelli were well organised and familiar to the maintainers. The drawings are in well labelled box files, organised in such a way as to represent the layout of the factory-floor. Hence, from these results alone it is not possible to say that a hypermedia information system will always produce a significant difference in the time taken to locate the information, when compared to a familiar, and well organised, paper-base information system.

Table 8-5 shows the average number of documents the users visited per task, the average length of time the user spent on each document, the number of occasions the users got lost, the number of short cuts or menus used, and in the case of the hypermedia application, the number of links followed.

The number of documents for the hypermedia application was simply the number of nodes displayed. The number of documents for the paper-based system was the number of manuals, the sections visited in the manuals, loose drawings and instruction sheets. This is a low estimate for the number of documents visited for the paper based system, as the users often flick through the manuals to find the information, hence it was difficult to record all

the pages visited. Therefore, only pages that the users dwelt on were counted as being visited. However, even with the underestimate of the paper-based system, statistically significant fewer documents were visited by the user to obtain the information they required when they used the hypermedia application. Similarly, on average users spent statistically significantly less time on each document. Coupled with the result that users got lost less often, and used the short cuts and menus more, this shows that the user found the system easier to use. This was reflected in the response to the questions from the questionnaires to ascertain how the user compared the ease of use of the two systems. The users show that that they preferred to use the hypermedia system and that these results were statistically significant, Table 8-6. Hence, the second null hypothesis can be rejected and the alternative hypothesis that the hypermedia system is easier to use than the paper based system can be accepted.

Although, the normalised scores increased in each category, see Figure 8-2, showing that the users felt that the system was more usable, there was not a general statistical difference between their answers to the complete questionnaires used after training and those after the timed trials. The general principles of the hypermedia system were explained to the users during the training program. The increased normalised scores from the questionnaires after the time trials suggests that the real benefits of using the hypermedia system only become apparent to the users when they can compare the use of the hypermedia system in their working environment and whilst undertaking familiar tasks.

8.4 Results from the second time trial.

The time trials were repeated to ensure that the results obtained were still valid after a period of approximately six months without assistance or input from the design team. Due to changes in personnel only five of the original nine maintainers were available to carry out the trial. An additional sixth maintainer was used in this trial. He was the senior apprentice who had now graduated to full shift team member. Exactly the same procedures, questionnaires and tasks were used as in the previous timed trial, presented above.

Maintainer Number	1	2	3	4	5	6
User	M	E	M	E	E	M
Media to be used First	H	H	P	P	H	H
Order of tasks	2,3,1	3,1,2	1,2,3	1,2,3	2,3,1	3,1,2

Table 8-7 Order of tasks for maintainers for second time trial.

Task	Type	Mean Time s (SD)	t-test
Task 1 Electrical	Paper	88.25 (62.51)	P=0.13
	Hypermedia	39.50 (6.34)	
Task 2 Electrical	Paper	149.0 (64.1)	P=0.08
	Hypermedia	53.5 (20.1)	
Task 3 Electrical	Paper	126.5 (82.7)	P=0.06
	Hypermedia	18.8 (5.0)	
Task 1 Mechanical	Paper	82.4 (20.4)	P<0.01
	Hypermedia	13.8 (3.6)	
Task 2 Mechanical	Paper	55.2 (30.4)	P<0.05
	Hypermedia	38.2 (36.3)	
Task 3 Mechanical	Paper	66.4 (15.06)	P<0.01
	Hypermedia	21.8 (2.49)	
All Tasks	Paper	137.5 (65.5)	P<0.001 ***
	Hypermedia	45.3 (26.1)	

Table 8-8 A summary of the results from second timed trial.

Task	Type	Mean Time s (SD)	t-test
All Tasks first timed trial	Paper	147.0 (82.8)	P<0.001 ***
	Hypermedia	51.0 (22.7)	
All Tasks Second timed trial	Paper	137.5 (65.5)	P<0.001 ***
	Hypermedia	45.3 (26.1)	

Table 8-9 A summary of the results from first and second timed trial.

	Number of documents visited		Time (s) spend on locating and studying each document		Number of occasions the user become lost		Number of short cuts /indexes		Number of links used .
	Paper	Hypermedia	Paper	Hypermedia	Paper	Hypermedia	Paper	Hypermedia	
Electrical					4	0	31	29	32
Mean	12.89	5.56	13.57	8.80	0.44	0.00	3.44	3.22	3.56
SD	5.88	2.40	5.12	1.45	0.53	0.00	2.74	1.20	2.01
Median	14.00	5.00	11.28	8.60	0.00	0.00	3.00	4.00	4.00
t-test	P< 0.001		P<0.05.						
Mechanical					2	0	14	18	24
Mean	12.80	4.44	12.80	8.99	12.80	0.00	12.80	2.00	2.67
SD	4.34	0.88	3.70	4.99	0.44	0.00	0.88	0.00	0.87
Median	10.00	5.00	10.60	7.20	0.00	0.00	2.00	2.00	3.00
t-test	P<0.01		P=0.204835						
All Tasks					6	0	45	47	56
Mean	12.00	5.00	12.33	8.90	0.33	0.00	2.50	2.67	3.11
SD	5.10	1.85	4.59	3.57	0.49	0.00	2.20	1.04	1.57
Median	11.00	5.00	11.20	7.90	0.00	0.00	2.00	2.00	3.00
t-test	P<0.001		P< 0.05						

Table 8-10 Usability Data per task from the second timed trial.

Questions	Paper Based		Hypermedia		Wilcoxon Signed Ranks Test
	Score	Mean (S.D.)	Score	Mean (S.D.)	
I would want to use on a regular basis	-2	-0.3 (1.0)	6	1.0 (0.0)	P<0.001
It was not frustrating to use	-6	-1.0 (0.0)	6	1.0 (0.0)	P<0.001
I found it straightforward to get to the information	-6	-1.0 (0.0)	6	1.0 (0.0)	P<0.001
There are not too many steps required to get to the information I needed	-6	-1.0 (0.0)	6	1.0 (0.0)	P<0.001
It would not get in the way of the task I was undertaking	-7	-1.2 (0.4)	6	1.0 (0.0)	P<0.001
I did not find it difficult to obtain the information I needed.	-7	-0.9 (1.0)	6	1.0 (0.0)	P<0.001
I did not become lost/ disorientated when using the computer-based system	-2	-0.3 (1.0)	6	1.0 (0.0)	P<0.001
Total	-36	-5.7 (0.7)	42	7.0 (0.0)	
Normalised	-0.83		1.00		

Table 8-11 A summary of the response to the questions comparing to the usability of the systems after the second timed trial.

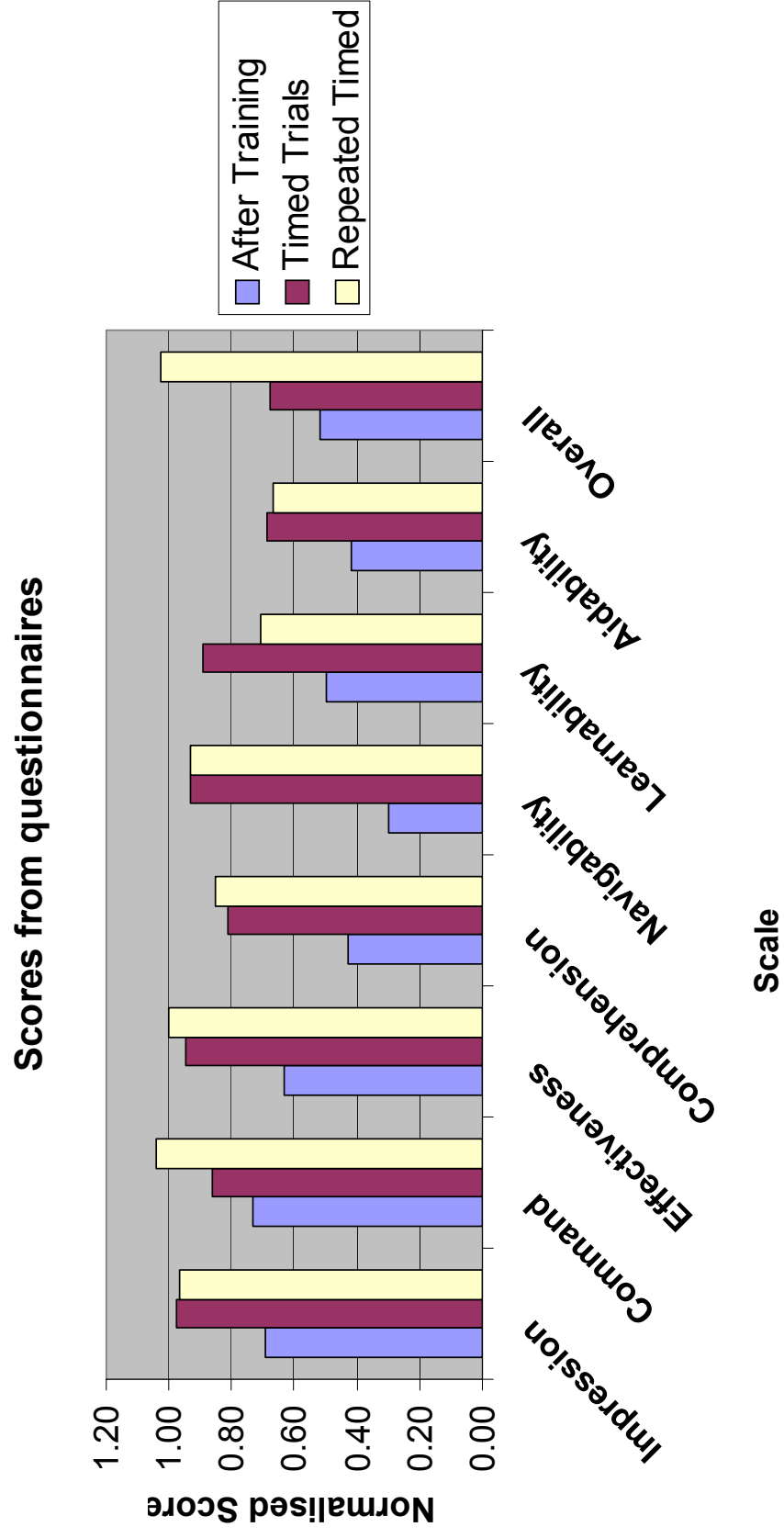


Figure 8-3 Chart of the difference between the normalised scores from the questionnaires.

8.4.1 Comments on the second timed trial.

The results from the second time trial showed that there was a continuing statistically significant difference between using the current information system at Pirelli and the case study hypermedia application. The users were continuing to find the information quicker using the hypermedia system, Table 8-8 shows that the average time to locate the information in all cases was less when using the hypermedia system, Table 8-9.

The time to complete the electrical and mechanical tasks continued to show statistical significance. While the over-all times and all the times for the mechanical tasks were statistical significance at the 5% level, it is not the case for the electrical tasks. That is to say, while the times are much quicker when using the hypermedia system for each of the individual electrical tasks, with such a small sample, chance cannot be ruled out. However when the times for all three electrical tasks are taken together, and giving a larger sample, there is a clear statistical significance between using the hypermedia system and the paper-based system.

When using the hypermedia system, the users visited fewer documents in order to find the information, as shown in Table 8-10. In addition, none of the users got lost while using the hypermedia system. However, a number of users found it difficult to obtain information without some assistance when using the paper-based system.

The response to the questionnaires continued to show that the users preferred the hypermedia system to the current information system, Table 8-11. In addition, the overall normalised score from the questionnaires increased, see Figure 8-3. Although in two of the categories, learnability and aidability, the scores were slightly less, than the first time trials, they were still much higher than the normalised scores after training.

Hence, the null hypotheses can still be rejected, since the hypermedia system, after the second timed trial, continued to be quicker and easier to use than the existing paper-based system.

8.5 Apprentice time trial.

The apprentice time trial was design to investigate whether the hypermedia system could be effective in helping someone who is unfamiliar with the paper-based system to locate information more easily.

The same tasks and questionnaires were used as in the other timed trials. The difference was that neither apprentice received any training prior to the trial, except for a quick demonstration of both information systems and a tour of the Supertension line. The apprentices complete all six tasks, see Table 8-12 for the timings and Table 8-13 for usability.

	Total time (s)	Mean (SD)	t-test
Paper	1554^a	155.40 (69.06)	P<0.001
Electronic	518	43.177 (32.10)	

a: value does not include timings from uncompleted tasks.

Table 8-12 Times for Apprentices

		Over-all	Mean (SD)
Documents visited	Paper	182^a	15.17 (4.50)
	Hypermedia	54	4.50 (1.00)
No of time lost	Paper	5	0.42 (0.51)
	Hypermedia	0	0.00 (0.00)
Short cuts /indexes	Paper	61^a	5.08 (3.78)
	Hypermedia	26	2.17 (0.39)
Links used	Hypermedia	42	3.67 (1.37)

a: value does not include uncompleted tasks.

Table 8-13 Usability data from Apprentices.

	Score	Total Normalised	Mean (SD)	Median	Mode
Hypermedia	9.00	0.64	0.64 (0.93)	1.00	1.00
Paper	-2.00	-0.14	-0.14 (1.03)	-1.00	-1.00

Table 8-14 The response to the questions on usability from the apprentices.

8.5.1 Comments on trials using apprentices.

The first apprentice was unable to complete the electrical tasks one and three on the paper based system, yet he did finish the tasks for the hypermedia system. The inability of the first apprentice to complete the tasks was in part due to unfamiliarity with the paper-based system. The second apprentice was able to complete these tasks, as he was told the location of the electrical information.

Both apprentices completed all the tasks on the hypermedia system more quickly than the paper-based system, see Table 8-12, again in approximately one-third of the time. They also found the paper-based system difficult to use. This was demonstrated by the number of documents visited, the number of times they got lost (see Table 8-13) and their replies to the questionnaires (see Table 8-13). They found the paper documentation difficult to use, partly due to unfamiliarity and to the lack of proper description given to manuals and box files. Hence, these results suggest that the hypermedia system may also be appropriate for training or induction of personnel to an unfamiliar process line. However, the sample is too small to make any general conclusions.

8.6 Summary

This chapter has presented the results of the user evaluation of the application produced for Pirelli cables.

All the Supertension Sheathing line personnel were trained to use the developed hypermedia application. In addition, personnel from the engineering and maintenance departments of Ford were also trained to use the hypermedia system.

The comments from the Ford group of users were similar to the comments from the maintenance group at Pirelli. The points raised by the users were:

- The information was required at the point of use.
- There was concern relating to the amount of information that could be displayed and still be legible. This highlights the problem encountered when moving from the printed to electronic media.
- The maintainers wanted more detailed equipment specific (rating) information, which went beyond what they had in the paper-based system.
- The maintainers wanted to be able to annotate drawings with changes or modifications.
- The computerised system would allow the maintainers to keep other records more conveniently, correcting the problem of using bits of paper that were forever getting lost.
- The users would like to publish to other users, useful or commonly used trails through the information space.

What this indicated was that there was a need to change the working practices as well as changing the way the system displayed the information.

The results from both the timed trials showed that there is a statistically significant difference between using the current information system at Pirelli and the proposed hypermedia system. That is, the users were able to find the information in about a third of the time when using the hypermedia system, they had to visit less documents, and got lost less often. In addition, the questionnaire responses showed that the users significantly preferred the hypermedia system to the current paper-based information system.

The increase in the scores from the questionnaires obtained from the maintainers at Pirelli, after they completed the timed trials, suggests that the trials had other advantages, beyond

just obtaining qualitative data. In that, they enabled the users to experience the advantages of using a hypermedia system, rather than just thinking about it.

The results from the trials using the apprentices showed that the hypermedia system was appropriate for training or induction of personnel to an unfamiliar process line.

These trials have fulfilled the object of carrying out the user evaluation, that is, an open hypermedia application could be used effectively on a factory floor.

Chapter 9.

Management Strategy.

Investment in hypermedia systems will have different benefits for individual industrial organisations. These benefits will range from allowing the organisation to just survive in the global market to improving the corporate image as a leader in their field.

This chapter identifies some of the benefits and considerations when introducing industrial hypermedia. In addition, this chapter presents a model for estimating the effort required to author an industrial hypermedia application and demonstrates how heuristics can be used to simplify the proposed model.

9.1 Strategic Considerations.

Strategic issues usually are of a long term view, with a wide impact on the organisation, the enduring effects of which are hard to reverse [Chapman 87]. However, it is not always necessary for technology to be leading edge to give the organisation a competitive edge [Hogbin 94]. The introduction of hypermedia should be seen in the context of an overall competitive strategy. In itself, hypermedia will not absolve the organisation from requiring change, focusing on customer needs, improving the quality of its products or services and continuing to develop new ones. Hogbin et al have also put forward a number of business principles and technology trends that suggest that investment in information technology (IT) may be beneficial. These are:

- Speed of access to information and faster communications gives rise to new business opportunities and helps raise productivity.

- The cost of people is rising and that of technology falling. In addition, the functions delivered by technology are increasing.
- Key business ratios must be maintained or improved. For example, ratios for expense, profitability, working capital etc.
- Further significant cost restructuring will only be achieved by redesigning business processes, and this will only be achieved with the aid of IT.

All change will involve cost but there is also a cost by not changing and standing still. One of the more important benefits from investment in IT, and yet one of the most difficult to quantify, relates to the organisations' market position and the income generated from that position. Investments which improve the quality of service to the customer, internal and external, or support new products or service may lead to an increase in market share or at least maintain it against strong competition.

Making decisions often relates to assessing the risk, especially within business IT investment [Down 94]. Risk identification is proactive and requires a high degree of judgement and perception, but once identified must be managed [Hogbin 94]. The general risks associated with software based projects are [Laudon 98].

- Benefits may not be obtained
- Costs may exceed budget
- Implementation exceeds the planned time frame.
- The actual technical performance is less than expected.

The simplest method in analysing the identified risks is by factorising the risk. That is assigning a value to its importance, value and likelihood [Down 94]. The object is to identify the high risk areas and assign personnel responsibility for managing the risk.

The central problem for the industrial strategist is to identify strategies which have desired characteristics of high return and low risk. This is demonstrated by using the technique called Strategic Portfolio Analysis [Chapman 88, Laudon 98]. The most desirable strategy for any organisation is one that is consistent with both its organisation and environment. That is, their organisational objectives, their other activities and available resources.

9.1.1 Changing Culture.

The introduction of new information systems into the industrial environment, especially those that require a different paradigm, has resulted in cultural changes within the working environment. For example Total Quality Management, Just-In-Time manufacture [Kirton 94], Total Maintenance Production [Counsell 99], or even new paper based systems such as BS EN ISO 9000 [Krane 99]. Therefore, it is realistic to expect that the introduction of hypermedia in an industrial environment would also result in a change in the working culture. What is clear from introduction of these systems is that changing the culture can be difficult and the result ill defined. Hence, plans for changing the culture tend to be ignored or left to end of a project. Any cultural change will require time and the commitment of senior management [Woodhouse 1993], without which most projects of this kind and size tend to fail. It is important to identify those elements of the workforce that are open to change, and to train and envision these people so that they become the 'Champions of Change'. Therefore, communication of the strategy is an essential component in changing the culture and practice of the organisation. The reason for, as much as what and how, the changes are to be implemented must be continually communicated at all levels of organisation. Finally, conflict is a necessary part of cultural change, and therefore should be dealt with quickly and not ignored.

9.2 Strategic Investment.

The reasons for investing in hypermedia information systems will vary between different organisations. This research has identified two distinct groups of investors, the suppliers and the users of the information. These may or may not be part of the same organisation.

The suppliers of information for the industrial environment are generally OEMs and departments dealing with writing technical information for other departments or for customers.

The users are simply any people who are required to use the information. For example, personnel on the factory floor using technical instruction and OEM's manuals, procurement personnel checking the specification of a component, etc.

9.2.1 Identification of Benefits.

There are a number of benefits from introducing a hypermedia application within an industrial environment. While the benefits can be easily identified, assigning a monetary value to the benefits is not so straight forward, hence, Laudon et al [Laudon 98] class the benefits of an information system as:

- **Tangible Benefits.** These benefits can be quantified and assigned a monetary value.
- **Intangible Benefits.** These benefits can be difficult, at least initially, to assign a monetary value.

Some of the benefits of a hypermedia system, when compared to a paper-based system, come directly from installing an electronic information system. These are then enhanced by the use of hyperlinks. The costs involved in producing an industrial hypermedia application are:

- Authoring, including document collection and conversion
- Computers system (if not already installed).
- Specialist software, including open hypermedia software.
- Training

There are a number of techniques used in indicating if the capital project, such as the introduction of hypermedia, will produce a financial reward [Chapman 88, Laudon 98].

- **Pay Back.** This is simply a measure of the time required to pay back the initial investment. However, it does not take into account the time value of money.
- **Rate of Return (ROI).** Calculates the rate of return on the investment, and allowing for depreciation on the cash inflows.
- **Net present value (NPV).** Calculates the worth of an investment in monetary terms, taking into account the costs, earnings, and the time value of money.
- **Internal Rate of Return (IRR).** Calculates the profit that an investment is expected to earn.

Organisations will invest capital into information systems for non-economic as well as economic reasons. Laudon et al [Laudon 1998] suggest that the problem with using only the financial view of investment, that is the system needs to produce significant returns to justify its cost, is that it is not always a simple task to estimate the benefits and associated costs. In addition, Laudon et al suggest that the difficulty in measuring intangible benefits leads any financial model to having an application bias, mainly due to costs and tangible

benefits not always occurring in the same time frame. Hence, results of financial models need to be brought into the wider context of organisational strategy.

<u>Tangible Benefits</u>	<u>Intangible Benefits</u>
<ol style="list-style-type: none"> 1. The saving of time in locating the information. 2. Not having to publish the paper copies, i.e. reducing printing cost and staff time. 3. Not having to distribute paper copies, both initial release and updated copies i.e. reducing staff time and for the suppliers a reduction in shipping costs 4. Customers or individual departments not having to control paper documents. 5. Reduce staff effort in documentation control 	<ol style="list-style-type: none"> 1. Increased user satisfaction by not getting lost, locating information more easily and directory 2. Ensure that users have the correct issue of the information appropriate to the task, at all times. 3. Reduction of errors due to easier cross-referencing between different information systems. 4. Providing and linking to additional useful information, where appropriate. 5. Not necessary to change the original format and hence easier system integration, by linking across different information systems. 6. Hyperlinks allows quick and effective cross-referencing. In addition, easier maintenance of document cross-referencing, after an update. 7. Opportunity cost (time), in being able to do something else. 8. Greater customer satisfaction and improved corporate image. 9. Help close the quality loop for many of the tasks performed by the operators. 10. Automatic data manipulation and dissemination. 11. Easier access to information from any point in the factory environment. 12. Improved quality of the document control system 13. Ensuring documents do not go missing. 14. The use of templates allows consistency of documents. 15. The legibility of the documents is improved. 16. The ability to capture and share information gained by experience

Table 9-1 A list of tangible and intangible benefits from introducing the developed hypermedia application.

9.3 Estimation of Authoring Effort.

In order to survive in today's markets, organisations have to be competitive requiring close examination of their costs. Hence, costing, or accounting, will often play an important part in management decisions [Arnold 90]. As authoring is a large cost factor when developing a hypermedia application, an ability to quantify the cost to author an application is required.

An important component in estimating the cost of authoring an industrial hypermedia application is the effort/labour required. In order to estimate the effort for authoring an industrial hypermedia application, while using the authoring methodology described in Chapter 4, it is essential to first understand the process. An effective way of achieving this is to model the process. A conceptual cost process model [BSI 92] is shown in Figure 9-1, and can be described as having:

- Inputs: Materials or data that are transformed by the process to create the output.
- Outputs: The results of the transformation of the inputs. The output includes material or data that conforms to the requirements, waste and process information.
- Controls: Inputs that define, regulate and/or influence the process. This embraces procedures, methods, plans, standards, policy, legislation and strategies.
- Resources: Contributing factors, which are not transformed to become outputs. That is people, equipment, materials, accommodation and environment requirements.

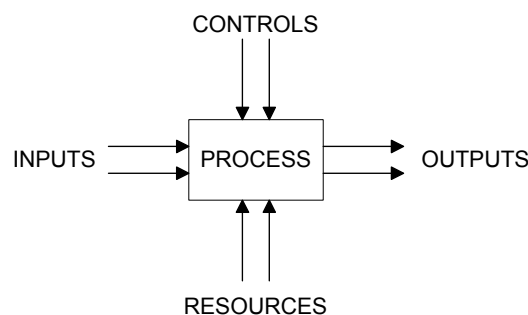


Figure 9-1 Conceptual Process Model

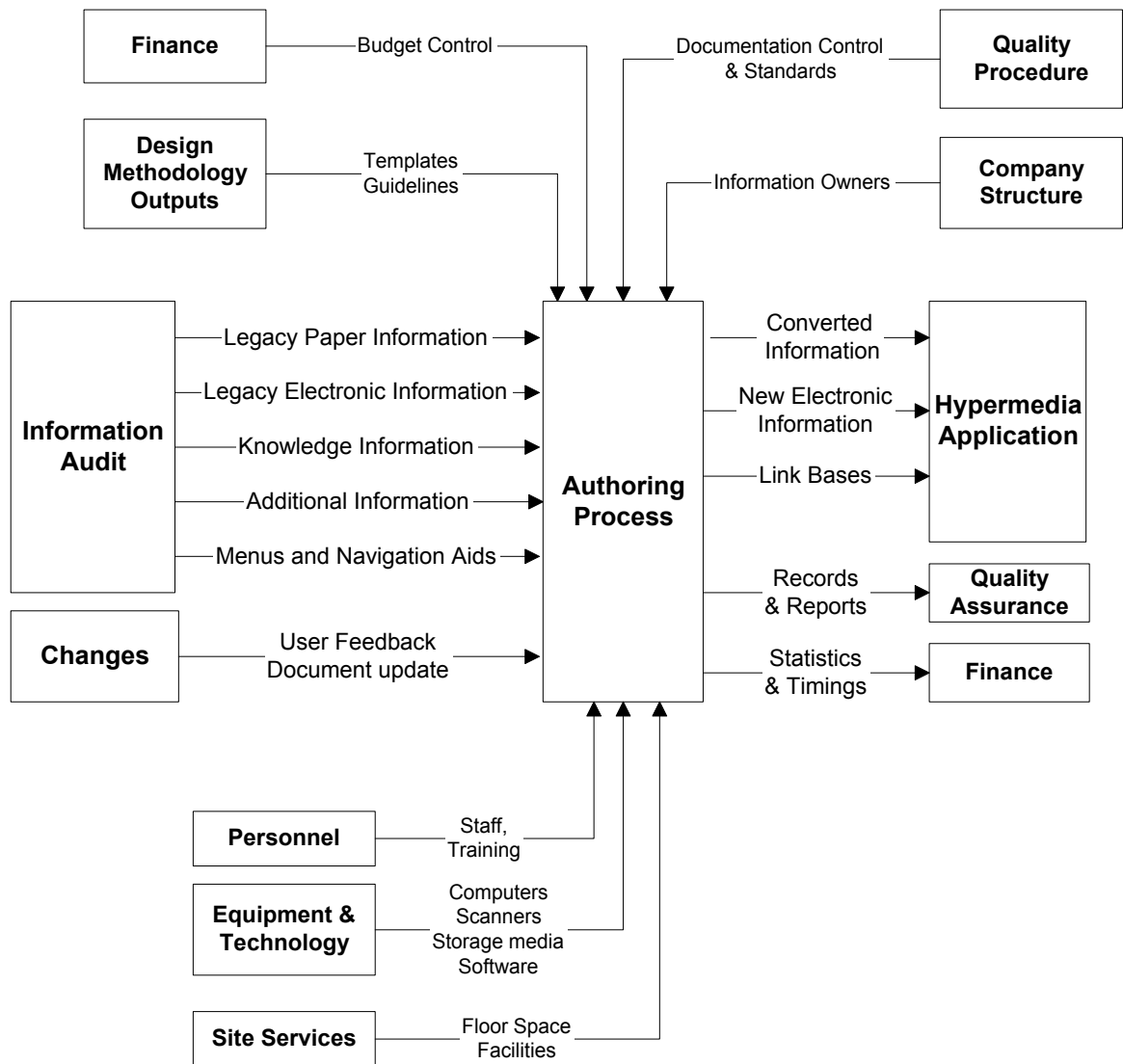


Figure 9-2 Authoring Process Model.

The amount of effort is dependent on how thoroughly the information audit was conducted. The information audit requires effort, hence there is a trade-off between the effort required to perform the audit and the effort to author the application. The combination of a detailed design and information audit will allow the authoring to be reduced to a process, where a set procedure is followed.

The complete process model for authoring an industrial hypermedia application is shown in Figure 9-2. From the model of the process, the effort required can be estimated. One method of estimation is called the engineering method [Arnold 90], as this is a detailed estimate based on the sum of the individual efforts from each activity in the process.

The authoring effort will be the sum of the efforts to produce each of the MHAs in an application. These are:

- Preparation of existing paper documents (E_P).
- Preparation of existing electronic documents (E_E).
- Creating new electronic information (E_N).
- Creating the structural links (E_{SL}).
- Creating cognitive and pedagogical links (E_{CP}).
- Maintaining records, reports and statistics (E_M).

These individual efforts are explored below and equations for the effort required to author an application are defined.

9.3.1 Existing Paper Documents.

The main effort with existing paper documentation is converting the information into an electronic format. This task can be sub-divided into five main activities, see Table 9-2.

Activity Number (i)	Activity Description
1	Collecting the information to be converted.
2	Converting the information from paper to a standard raster format.
3	Cleaning-up the information after conversion.
4	Processing the information into a vector format.
5	Saving the information with appropriate file names and file hierarchy

Table 9-2 List activities associate with preparing paper documents

As some documents only need to be in the raster format supplied by the conversion process, while others will need to be converted into a vector format, for example ASCII text using OCR techniques, not all documents require the final activity.

Paper documents that require retyping, drawings electronically redrafted, or forms converted to electronic data entry, can be classed as new electronic documents and hence the effort is calculated separately.

The conversion process can be sub-contracted to any number of companies that offer a bureau service. These companies will also do some of the post conversion tidying-up and the effort for correcting the converted documents is therefore reduced. However the cost is not zero and must be taken into account in the cost model. Where there are a significant number of documents converted into electronic information, sampling can be introduced to

the checking process. The sampling should be carried out in accordance with a recognised statistical process, for example BS 6001 [BSI 96].

Therefore, the effort required to deal with the paper information (**Ep**) is the sum of the effort for gathering, converting, correcting, and processing the paper information. When estimating the time to carry out each process it is assumed that time is included for verifying the work.

The individual processes that make up the converting of paper based information to electronic information depend on: -

- The number of single A4 sheets of paper to be involved in the activity (**Si**). For sheets larger than A4, an equivalent is given, for example, an A3 sheet is equivalent to two A4 sheets, an A0 sheet is equivalent to eight A4 sheets, etc.
- The average time taken to perform the activity (**Ti**).

The effort is expressed as: -

$$Ep = \sum_{i=Activity\ 1\ to\ 5} [S_i * T_i] \quad 9-1$$

9.3.2 Existing Electronic Documents.

The existing electronic information requires a common look and feel. In addition, the majority of existing electronic information has been written for the paper paradigm. Therefore, the reader only obtains the full benefits of the document layout when the document is printed. Hence, essential documents need to conform to the templates designed by the designers for the appropriate electronic format. This will not only ensure that they are readable in the electronic format but also aid link generation and screen management. In addition, the effort required to ensure that the converted paper documents conform to the required standard must be included within this calculation. Another part of the effort required would be to dissect long documents into information nodes and assign meaningful labels to each node. The effort required for existing electronic information is summarised in Table 9-3.

Activity Number (j)	Processes for asset electronic information
1	Conversion of electronic documents to standard templates
2	Dissections of long documents into appropriate lengths.

Table 9-3 List of activities associate with existing electronic documents

The effort required to process the existing electronic (E_E) information as:

9-2

$$E_E = \sum_{j = \text{process 1 to 2}} [Da_j * T_j]$$

where Da is the number of existing electronic documents, and T_j the average time taken to perform the activity. The number of documents in each process may not be the same.

It is assumed that the length of documents are statistically normally distributed, and hence the average size can be used to calculate the effort required. If this is not the case then a separate time for the average length of each different type of document requires calculating.

9.3.3 New Electronic Information.

A significant amount of information within the working environment is held as corporate knowledge. That is information that is known to a person or group of people, yet is vital for the smooth running of the organisation, but is not actually recorded. Therefore, this information first has to be collected, then entered into the system. In addition, information that is useful, but was not available, can now be added. Obviously, it is up to the management team to ensure that the request to add new information is within the scope of the application.

Therefore, the effort will vary with the number of different types of information (I) and the number of pieces of information of that type. T_k is the average time taken to perform the activity. If N is the number of new nodes that are required to be created, then the effort required to produce the new information (E_N) can be calculated as:

9-3

$$E_N = \left[N * T_{\text{Gather New Information}} \right] + \sum_{k=1 \text{ to } I} [N_k * T_k]$$

This relationship can also be used to include paper documents that are retyped, drawings that are electronically redrafted, and forms that are converted to electronic data entry.

9.3.4 Structural Links.

Once the information is in the correct format, linking may begin. The first and easiest is the structural links, as this is an administrative task. This should be an automated process especially where the documents conform to the standard templates. The structural linking is carried out usually on a document or set of nodes, hence the effort required is, on average, the same irrespective of the size of the document, and is only dependent on the number of documents, Dn . $T_{Automated}$ is the average time taken to generate the links automatically. In addition, effort is required to supervise and organise the process, and to create the structural links. The manual linking is required to link menus and other small groups of documents that do not conform to any standard templates and depends on the number of links (L_S) required. T_{Manual} is the average time taken to produce the links manually. In addition, effort is required to make a number of link databases (B_S) for both the manual and automatic linking processes, and $T_{Linkbases}$ is the average time taken to make the linkbases. All documents require registering with the hypermedia document management system and grouped into a number of MHAs (T_M). The effort can therefore be expressed as: -

$$E_{SL} = [Dn * T_{Automated}] + [L_S * T_{Manual}] + [B_S * T_{Linkbases}] + [T_M] \quad 9-4$$

An estimate of the number of structural links, L_S , within a MHA, can be determined from the number of:

- Nodes, figures, and tables.
- Items in indexes and menus.
- References to external information.
- Items on a drawing and the reference to specifications.
- Items on the material lists multiplied by the number of related documents. For example, items on a material will be linked to at least one drawing and a specification.

9.3.5 Cognitive And Pedagogical Links (E_{CP}).

The effort here involves experts from the relative disciplines and departments making the associations that are not obvious. The effort will be dependent on the number of links (L_{CP}) required to be made and the number of link bases (B_{cp}) required. In addition, included in this effort is the time taken to produce the link clusters (L_{LC}) [Crowder 98]. T_L

T_{CP} and T_{LC} are the average time taken to perform the respective activity. The cognitive and pedagogical effort is expressed as: -

$$E_{CP} = [L_{CP} * T_L] + [B_{cp} * T_{LB}] + [L_{CP} * T_{LC}] \quad 9-5$$

9.3.6 Records, Reports and Statistics.

In an industrial environment, it is essential that the documentation audit trail be maintained. Hence, all documents that have been changed or created must be recorded in the company's document control system, Nc is defined as the number of nodes changed. If the effort model is to be managed effectively it will need to be monitored and actual times compared with forecast times, in order to keep it within budget. Hence, the requirement to record statistical information, represented by the number of statistical records kept, $Stat$. In addition, it is essential, for auditing purposes, to report on the progress of the process with R being the number of reports that must be written. $T_{Records}$, $T_{Statistics}$ and T_{Report} are the cumulative average time taken to perform the respective activity. The effort is expressed as: -

$$E_M = [Nc * T_{Records}] + [Stat * T_{Statistic}] + [R * T_{Reports}] \quad 9-6$$

9.3.7 Total effort

The total effort for authoring a MHA is:

$$Total \ Authoring \ Effort = \sum_{For \ each \ MHA} [(E_P + E_E + E_N + E_{SL} + E_{CP} + E_M)] \quad 9-7$$

9.4 Using heuristics to estimate the effort.

The method of calculating the effort, used above, is very detailed. However, the process of carrying out the detailed estimating itself requires effort and therefore is an overhead. In addition, once the effort of a number of hypermedia applications have been costed and verified, it is then possible to use the data to estimate the effort required to produce similar size applications. This type of effort and then costing is referred to as historical cost-based estimation [Arnold 90].

A hypermedia application is a complex entity to define accurately. It is not just a matter of the number of documents and links, but also the way in which the application is linked together and the user guided through the application. Botafogo et al [Botafogo 92] defines the amount of cross-referencing as compactness. Their method of calculation is applicable only to completed applications. In addition, Botafogo et al assumed bi-directional links and did not allow for the concept of generic links or link clusters.

Mendes [Mendes 99] has demonstrated that the larger the hyperdocument size, or the greater the connectivity (number of links), or the higher the compactness, the more time consuming the development of an application. However, while she showed a correlation, Mendes was unable to qualify this by giving a relationship for size/complexity to effort.

9.4.1 Estimating the variables.

MHAs are usually much smaller in size than the final hypermedia applications. To ensure accuracy of comparison, comparisons should be made between MHAs rather than complete applications. It is not advisable to compare a similar size MHA consisting of background information, and one consisting of drawings and manufacturing information, as generally the latter will have a much higher level of cross-referencing.

The first step is to identify those variables that will describe the application accurately enough for a realistic estimate of the effort required. The important variables to be estimated are:

1. **Number and type of nodes requiring effort:** In the case of electronic information that is already in the style required, the number of nodes is the number of files. However, where the information is in a non-electronic format or of an incorrect style the number of nodes can be estimated by adding together:
 - The number of indexes. The indexes are menus, drawing lists, parts lists, etc
 - The number of drawings, videos, sound files etc.
 - The number of Manuals, then multiplying this by the number of chapters and the number of chapter sections.
 - The number of instruction sheets multiplied by the number of pages. The instruction sheets include set-up procedures, check list and other loose-leaf instruction sheets.

2. **Compactness of Structural Links:** The compactness can be estimated as the number of links per node. Estimating the actual number of links can be time consuming. Hence, a simple weighting system can be used to estimate the compactness, see Table 9-4.

i	Linking type X	Non	Partial	Complete
1	Structural linking to figures, tables, indexes, references to external documents, etc	0	1	2
2	Items on a drawings (embedded and external) referred to in the text linked	0	1	2
3	Linking of drawing or materials list (one link per item)	0	1	2
4	Linking of materials list (more than one link per item)	0	1	2

Table 9-4 Weighting for Linking factor used to represent link compactness.

The Linking factor can be expressed as:

$$Linking\ Factor = \left(1 + \sum_{i=1}^4 X_i \right) \quad 9-8$$

There is minimum weighting of one, this is to account for one link per node, to this is added the score of each row in Table 9-4, the maximum score for each row is two, the minimum is zero. The possible values for the link factor weighting ranges from 1 to 9, representing a low compactness to a very highly compact MHA.

9.4.2 Estimating the effort.

From a completed MHA, it is quite simple to obtain the number of nodes, the number of structural links, compactness, complexity and time taken to complete. Based on the historical data gather while completing MHAs a ratio of the time to produce the different types of nodes, listed above, can be gained, see Table 9-5. The ratios in Table 9-5 are derived by dividing the initial time for each operation by the longest time. The actual values used in Table 9-5 are based on data gathered while producing the industrial hypermedia applications described in Chapter 5.

A rough estimate of the time to author a particular MHA can obtained by multiplying the number and types of hypermedia nodes by the appropriate ratios (Table 9-5) and then by the linking factor associated with the link compactness (Table 9-4).

Task	Time (minutes)	Ratio
New Video	120	1.00
New Drawings	60	0.50
Scan TextDocuments	30	0.25
Produce Guided Tours	30	0.25
Scan Drawings	27	0.23
New List/Menus	24	0.20
Produce MHA	15	0.12
Convert Drawings	15	0.12
Produce Thumb Nail Sketches	12	0.1
Convert Text	12	0.1
ProduceLinkbases	12	0.1
Convert Lists	9	0.08

Table 9-5 Tabel of ratios, based on historical data of effort required.

Once the estimation using heuristics has been applied to the completed MHAs, then a comparison with the actual times can be made, see Table 9-6. The results can then be plotted on a scatter diagram and a best-fit curve can be fitted using linear regression, see Figure 9-3. This will give the management team some idea of the error.

MHA	Heuristic			Engineer	Error Hrs
	Ratio Total	Linking Factor	Total Hrs	Total Hrs	
LCU	18.25	3	54.75	54.50	0.25
Training	14.57	2	29.14	28.42	0.72
Extruder	13.41	4	53.64	56.12	-2.48
Siemens Motor	10.48	2	20.96	23.70	-2.74
Crosshead	8.57	4	34.28	34.79	-0.51
Caterpuller	7.28	3	21.84	20.23	1.61
Auto-Flang	6.02	4	24.08	27.96	-3.88
LCU Extension	4.62	2	9.24	9.48	-0.24
Technical Instruction	3.38	3	10.14	7.45	2.69
Installation	3.04	3	9.12	8.15	0.97
Gear Box	2.51	5	12.55	10.63	1.92
Stripping	2.24	9	20.16	17.32	2.84
Eurotherm DC Cabinet	1.62	5	8.1	7.21	0.89
Cleaning Station	1.42	1	1.42	2.78	-1.36
GE Head	1.2	2	2.4	2.77	-0.37
DC Cabinet	0.9	1	0.9	2.13	-1.23

Table 9-6 Demonstration of estimated effort for producing MHAs.

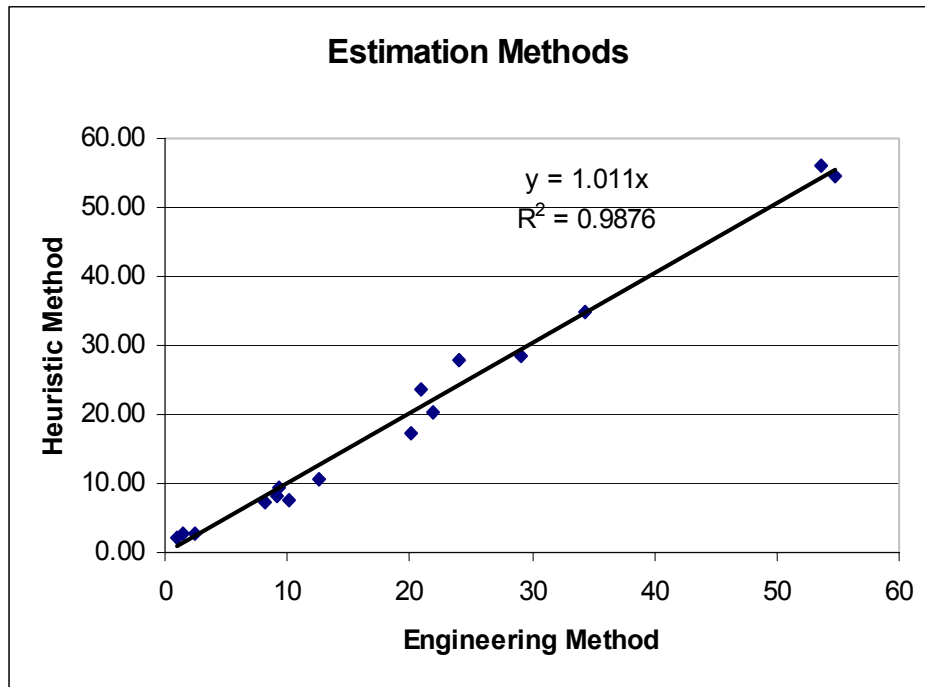


Figure 9-3 Graph of estimated times plus linear regression

The analysis of the variance (ANOVA) showed a coefficient of determination (R^2) of 0.976, this shows that there is a strong positive correlation between the estimate using heuristic and the detailed estimate using actual times [Bryman 90], details of analysis is presented in Appendix H.

Generally, where there is significant difference between the methods of estimation, that is the gradient of the line of best fit varies significantly from one, then the ratios given in Table 9-5 may be adjusted by multiplied by the gradient, to correct the error.

9.5 Costs for Authoring.

Within the literature, there are estimates of effort and cost for design of multimedia applications [Lechtenberg 98], but not for industrial hypermedia. The obvious difference, between multimedia and hypermedia, is that with hypermedia the emphasis is on the linking aspects of the production. In addition, multimedia applications tend to be smaller and hence the cost model focuses on the design process.

Once the effort required has been calculated, then the cost of the cost of authoring the application can be estimated.

The total cost of the authoring process is:

$$\text{Total Authoring Cost} = C_O + \sum_{\text{For each MHA}} [(E_P + E_E + E_N + E_{SL} + E_{CP} + E_M) * C_E] \quad \mathbf{9-9}$$

Where C_O are the overhead costs, and C_E the cost of employment.

The method of allocating costs will vary between organisation. However, the basic procedure is to take the effort and multiply it by the cost of employment. There is a cost of employment other than the salary paid to the employees, which includes the employer's National Insurance contribution, pension fund contributions, health and other insurances. It is preferable to calculate an average hourly rate of employment and add this to the hourly rate of the workers salary to produce a cost of employment [Drury 96]. Hence, it is necessary to calculate the cost of employment for the different salary scales or bands for the employees involved in the authoring process. In the first instant it may be sufficient to assume that the people employed in the task are paid the same. However, this is rarely the case due to factors such as full or part time employment, length of time served, seniority, etc. Hence, the extent to which these factors are taken into account will be related to the accuracy of the cost estimation required.

From the process from the process model, Figure 9-2, in addition to effort, there are additional costs come from, site services, materials and capital equipment required to undertake the process.

The site services are often termed the overhead costs. Overheads are those costs that cannot be directly assigned to the cost object such as product, process, or customer group [Drury 96]. Included in this cost are the cost of services, such as, lighting, heating, building maintenance, rent for floor space and the according proportion of the business rate. The traditional method of allocating the overhead costs is to divide the overhead cost among the various cost centres of the organisation. Each cost centre will then further apportion the cost among each of its activities. This method works well for cost accounting especially where the overheads are small in relation to the direct cost. However, when these overhead costs are greater than the direct costs, disparate allocation of overhead costs take place. Hence, a small but increasing number of engineering companies are changing over to activity based costing to allocate the overheads, especially when costing is to be used for management decisions [Moore 98]. Another method commonly used in estimation of costs

is to allocate a figure for overhead costs based on a function of the cumulative labour costs i.e. an additional forty-percent for example. The difficulty comes in estimating the indirect costs of such items as insurances, maintenance and power. There is an additional process cost, to account for variable overheads, which are unique to the process itself. These include such cost as the cost of managing and supervising the process, the materials and power consumed in the process, the cost of any subcontracted work etc. Most companies will use a multiplier to account for these costs. What is clear is that different companies will use different methods of allocating these costs. However the result is still the same, which is a fixed figure that represents the overhead costs.

In cost accounting, when costing equipment, a depreciation figure is used to spread the cost of equipment over a number of years [Reynolds 92]. The 'life term' of the equipment is chosen based on the nature of the equipment. Relative to the factory process machinery, the life term of computer equipment is generally short, that is less than five years. The type of depreciation can be a constant amount that allows for scrap at the end, or a constant fraction of the residual amount, producing larger depreciation values in the early stages. However, for cost forecasting it makes more sense to include the full cost of the equipment, including the cost of maintenance agreements, shipping, insurances, etc. In addition, the actual cost of purchasing equipment can be spread by the use of lease-purchase agreements, in which the company leases the equipment for a set period. If the company keeps the equipment to the end of the agreement, they will own the equipment, prior to which they can return the equipment as in any other leasing agreement.

The cost of the information audit should be included. The rationale is, that the effort required to perform the audit is an integral part of the authoring methodology and has a direct effect on the efficiency of the authoring process. A poor audit will result in a greater effort in the authoring process.

9.6 Learning Curve Effect

When people are first introduced to a task, they frequently take longer to perform that task than when they have repeated the task a number of times. This is known as the learning-curve effect [Drury 96]. The learning curve effect can only be applied to direct labour or variable overheads that are directly effected by labour effort. The learning curve is expressed as:

$$T = aX^b \quad 9-10$$

Where T is the cumulative average of the time required to carry out the task X times and a is the time required to carry out the task the first time. The exponential, b , is defined as,

$$b = \frac{\ln(\text{learning rate})}{\ln 2} \quad 9-11$$

and, b will range between -1 and 0. The learning curve is based on real world observations and hence the relationships described are empirical [Arnold 90]. The learning rate can vary between 65% and 90% in the early stages of production, and levels out to reach a steady state in which no further reductions in the time to perform the tasks by learning can be achieved. There are tables available to aid applying the learning curve. The tables give the unit time and total unit time for different learning curves against number of times the task is performed. The learning curve can be applied to each of the input tasks identified in the process model.

Using a different number of people will not effect equation 9-9. That is the effort will be divided by the number of people used and at the same time the cost of employment is multiplied by the number of people used on each task, hence they cancel each other out. However, each person carrying out the task will be subject to the learning curve effect. For example, in the scanning process of S sheets, if the learning curve is applied directly it assumes a time base on one person carrying out the task. Therefore the more people assigned to the task the less sheets they actual scan and hence the time they require to carry out the task will not be as quick. Common sense is required here, as it is not possible to allocate more people to a task then there is equipment to complete the task. The simplest method is to divide the total number of paper sheets to be scanned by the number of people directly involved in the process.

Hence, equation 9-10 can be written as: -

$$Y_x = aX^b P^{-b} \quad 9-12$$

This will have the effect of slightly increasing the effort time allowing for individual learning. Similarly, there is a natural mechanical limit to the learning rate, this is a result of:

- Ergonomics, that is the number of movements by the human to perform the operations will result in a limit to the speed of operation.
- Mechanical limits of the machine, for example the scanning process will be limited by the speed of the scanner to scan a document and by the speed of the processor/program to convert from a raster to a vector format.

Therefore the learning curve must take this into account. Hence

$$Y_x > C_{ML} \quad \text{9-13}$$

Where C_{ML} is a constant representing the mechanical limit of the process.

The initial timings will usually be based on an average time to complete the task. Hence, there will be a tolerance to each of the tasks. The accumulative tolerance will be quite large when compared to the time to complete the MHA. However, by using statistical tolerancing, the overall tolerance for the time to author is much less than the arithmetic sum of the tolerance [Burr 76].

$$T_T = \sqrt{\sum (T_I^2 * N_T)} \quad \text{9-14}$$

Where:

T_T = The total tolerance

T_I = The individual tolerance for each operation.

N_T = the number of times the operation is performed.

9.7 Example Costs

The times used in the example present here are based on the time required to produce the application reported in chapter 5.

The total effort equates to 14 weeks of an administrative person's time, see Table 9-7, and 1.3 weeks of an experts time. The effort assumes that only one person will carry out each task and that all work is undertaken 'in-house'. It is also assumes that the design phase and information audit has identified all the information required and the file structures required to store the information. That is the operator only needs to follow the procedure, and not decide how or where to save information.

Effort	Task	Number	Initial Time (Hours)	Effort Hours (with Learning Curve @ 95 %)
Asset Paper				
Gathering Information	All	368	0.27	63.38
Conversion	Text	168	0.10	11.50
	Images	200	0.12	15.77
Cleaning up	Text	168	0.17	19.16
	Images	200	0.25	33.78
Processing	OCR	168	0.08	9.58
	Correcting OCR	168	0.17	19.16
	thumbnail	30	0.20	4.66
	Scaling Images	200	0.08	11.26
New . Information				
	video	4	4.00	14.44
	Drawings	2	1.00	1.90
	Lists/Menus	10	0.42	3.51
Asset Electronic				
Look & Feel	Text	221	0.13	19.76
	List	11	0.10	0.92
	Drawings	277	0.25	45.67
Structural Linking				
	Automatic	1	0.17	0.17
	Manual	3500	0.08	159.45
	Linkbases	45	0.20	6.79
	MHAs	26	0.25	5.11
	Guided tours	15	0.50	6.14
Administration				
	Document Registration	890	0.05	26.92
Total Hours Admin				479.05
Cognitive Linking				
	Manual	1000	0.05	29.99
	Linkbases	30	0.25	5.83
	Clusters	50	0.42	15.60
Total hour Expert				51.42

Table 9-7 Table of effort required to author the application

The process of scanning the documents essentially involves using a computer. Hence, the normal Health and Safety rules apply for computer operators. In addition, regular breaks from viewing the screen must be allowed, therefore a working week for cost estimation has been taken as 30 hours.

The example cost of the effort can be calculated by using the standard pay scales for cost of employment and the costing can be broken down into: -

1. The additional process cost is calculated as twenty percent of the cost of each effort activity.
2. The cost of auditing, which is twenty person weeks, charged at the expert cost of employment.
3. The overhead cost is based on the standard university costing of forty percent of the sum of the addition process cost and the cost of each of the effort activity.
4. The equipment costs is based on: -
 - Two networked Pentium II with about a 7GB hard drive.
 - Data capture hardware and software for paper and microfiche asset information.
 - Appropriate software, this includes word-processing, databases, computer aided drafting etc.
 - The cost of PC support.

Activity	Cost £
Process	5328
Additional	1598
audit	10000
Overheads	6771
Equipment	5000
Total	28697

Table 9-8 Sample costing of the authoring process.

9.7.1 Cost-benefits analysis.

In addition to the cost of producing the original application there will be the need to maintain the system. In the case of Pirelli, this is a small marginal cost as there is already a department set-up to maintain the Intranet infrastructure. Hence, for the purpose of this analysis, maintenance cost will be excluded. A similar argument, can be applied to installation costs and management costs.

In Table 9-1 a number of tangible benefits were identified. The tangible benefits can be viewed as time saving, and hence allocated a cost:

1. The saving of a third of the time to locate the information required.
2. Reduce staff effort in documentation control in:

- A time saving in not having to publish the paper copies, therefore a reduction in the re-printing cost and staff time.
 - A time saving in not having to distribute paper copies, both initial release and updated copies i.e. reducing staff time and for the suppliers a reduction in shipping costs.
3. A time saving for the customers or individual departments not having to control paper documents.
 4. Opportunity cost for staff to do other more productive work.

If detailed benefit costs are required then detailed audits of each benefit is required. In this example analysis, estimates of the savings are used.

The time saving during maintenance can be translated on average to be 1 minute per task. From the documentation, the maintainers carried out on average 148 tasks on routine maintenance alone. Similar timing could be used for all information requested for the Supertension sheathing line. That is each maintainer and shift operator makes a minute saving on retrieving the information, and each accesses the information only twice in a shift. This will equate to 766.3 hrs of time saved per year.

There were twenty-two manuals in the application described in chapter 5 and over 200 drawings. If a conservative estimate of 20 minutes is taken for the issue of a manual and 15 minutes for its distribution, with a further 10 minutes for the recipient to register receipt and store appropriately, this will approximate a saving of 16.5 hours. Similarly with the drawings if a conservative estimate is made of 20 minutes for the whole process, a saving of 66.6 hours can be made. If after initial issue, ten percent of drawings and manuals are to be amended and re-issued, per year, a further 8.3 hours can be saved.

The opportunity cost is a difficult direct benefit to measure as not all the time saved, will be used to do something else more productive [Laudon 98]. Laudon et al suggests that 70 % is a realistic figure for time gained in other productive work. The total cost benefit arising from these tangible benefits is summarised in Table 9-9, the same hourly rate is used in both the estimation of the authoring cost and cost-benefits.

Task	Hour	Hours x Opportunity	Equivalent Costs £
Information Retrieval	776.3	1319.7	12245
Issuing Documents	91.4	155.3	1449
Total			13694

Table 9-9 The tangible cost benefits.

From these figures a simple pay-back period can be calculated using:

$$\text{Number of years to pay back} = \frac{\text{Original Investment}}{\text{Annual net cash inflow}}$$

9-15

This gives a pay-back period, for tangible cost only, of 2.1 years.

However, the benefits are much greater than just the tangible benefits, as can be seen from Table 9-1, and hence the payback period will be much less.

9.7.2 Problems of costing intangible benefits.

One of the more important benefits from investment in hypermedia, and yet one of the most difficult to quantify, relates to the organisation's market position and the income generated from that position. This market position is one often of image, and historical performance. These attributes are often related to the quality of the product, ability to deliver on time and costs. Therefore any system that can add to the quality of the product, or quality image of the product is a benefit.

Some of the intangible benefits are easier to assign a value than others. Those that are easier to assign a value are those that can be directly or indirectly measure, often a detail audit of existing information is all that is required. These can be grouped as:

- Those relating to training:- The ability to capture and share information gained by experience.
- Those relating to the shop-floor:- Automatic data manipulation and dissemination; closing the quality loop and the reduction of errors due to easier cross-referencing between different information systems; ensuring documents do not go 'missing'; improved quality of the document control system.

Those benefits that are the hardest to assign a value are those based on perception. Hence the estimate becomes more a matter of expertise (experience and judgement) than facts. For instance the increased user satisfaction by not getting lost, or locating information more easily and directly.

In between sit the other benefits that require an audit and yet still require a considerable amount of judgement and expertise. These are for example,

- Users will have the correct issue of the information appropriate to the task, at all times;
- The use of templates allows consistency of documents;
- Providing and linking to additional useful information, where appropriate;
- The legibility of the documents is improved;
- Not necessary to change the original format and hence easier system integration, by linking across different information systems;
- Hyperlinks allow quick and effective cross-referencing. In addition, easier maintenance of document cross-referencing after an update;
- Easier access to information from any point in the factory environment.

9.8 Summary

In practice, it must be recognised that while the majority of problems to be overcome, when introducing an industrial open hypermedia system, are technical some of the most difficult relate to the inertia of the management culture within the organisation. Hence, this chapter has examined the strategic benefits and considerations when introducing industrial strength hypermedia.

Based on the authoring methodology presented in Chapter 4, a model that allows an estimation of the effort or time to produce the hypermedia application is presented. The actual figures and paths through the model will depend largely on the decision made by the team responsible for the authoring process. The total effort is the sum of each of the individual efforts given in equations 9-1 to 9-6.

After an appropriate number of MHAs have been accurately costed and verified. The data can then be used to estimate the time required to author similar MHAs. This has been demonstrated using timings gained from the author's experience in producing an industrial hypermedia application.

Once the effort has been calculated, the cost of the process can then be ascertained. The cost factors of the hypermedia application are mainly the factory overhead costs, the cost of employment, the equipment costs and additional overhead cost applicable only to the process.

The cost benefits analysis shows that the introduction of a large-scale industrial hypermedia application should pay for itself in 2.1 years. However, as allocating costs to the benefits can be a difficult process, this period may be much shorter. While allocating cost to tangible benefits is relative straightforward, this is not the case with intangible benefits. Especially those based on perception, where judgement and experience rather than hard facts are required.

Chapter 10.

Conclusions and Future work.

10.1 Conclusions.

The development of an application for the factory floor, at Pirelli Cables, has demonstrated that hypermedia can be used to aid the provision of up to date and easily accessible information. The approach taken of using a single process line to demonstrate the concept of hypermedia information resource management for the whole factory proved to be effective. The research reached the following conclusions:

- I. When designing or developing a hypermedia application, one cannot ignore the requirement and constraints of the industrial environment, namely, the existing information system with their structure, content, and access methods, legacy systems, and the wide range of user requirements. As these requirements are not accounted for in existing methodologies and models, a new design methodology for designing large-scale industrial hypermedia applications was developed.
- II. In order to reduce the cognitive overload to authors while developing a large-scale industrial hypermedia application a modular approach was used. The developed application was based on Modular Hypermedia Applications (MHAs). Each MHA contains all the necessary engineering and hypermedia specific information for a single entity, defined by the author. MHAs enhance the portability, maintainability and scalability of the information system.

- III. The reality is that there is still an enormous amount of information held in non-electronic formats that requires converting in to an electronic format and integrated into the system. Similarly, there is a significant amount of information that is held as 'corporate knowledge' that also requires capture. The implementation of the design and authoring methodology is made significantly easier when the documentation is in electronic format.
- IV. The largest cost in producing a hypermedia application is the authoring of the MHAs. Therefore to reduce this cost the research has examined and demonstrated ways of automatically generating structural links and dissecting existing long electronic documents.
- V. The industrial hypermedia application must allow personnel with different and varying computer skills effective and controlled access to the required information. Screen Handler Enabling Process (SHEP) provided an appropriate user interface, which had a common look and feel yet allows the different group of users, with different abilities, access to the appropriate information.
- VI. The evaluation methodology developed satisfied the requirements of the industrial environment for a methodology that limits involvement of factory floor personnel, without having to use expensive user laboratories and yet measures the effectiveness and ease of use of the application.
- VII. The use of discounted usability evaluation proved a quick and cost effective technique to finding usability problems, in the first instance. The evaluation showed that to use the technique to evaluate a hypermedia application, an extra principle of '*Provide Navigational Aids*' is required to explicitly examine this feature of hypermedia applications. The evaluation also showed the use of the toolbar to be an effective method of providing short cuts. It was found that the analysis of the results must include a weighting categorisation of the observation and not just a factual recording. In addition, the observer needs to pay close attention to general comments, that on the surface may appear superfluous, yet increase in importance when repeated in other scenarios or by other experts.

- VIII. The discounted usability evaluation process also proved to be a useful method for gaining the ownership of the project by the line management. Similarly, the results from the questionnaires suggest that performing the time trials enabled the users to experience the advantages of using a hypermedia application.
- IX. The results from both of the timed trials showed that there is a statistically significant difference between using the current information system at Pirelli and the proposed hypermedia system. That is the users were not only able to find the information in about a third of the time when using the hypermedia system, they had to visit less documents, and got lost less often. In addition, from the questionnaires they showed that they significantly preferred the hypermedia system to the current information system.
- X. The results from the trials using the apprentices showed that the hypermedia system should also be appropriate for training or induction of personnel to an unfamiliar process line.
- XI. The introduction of industrial strength hypermedia requires a paradigm shift, from the paper document paradigm to the electronic. In practice, some of the most difficult problems to be overcome while introducing an industrial hypermedia application relate to the possible inertia of the management culture within the organisation. Hence, the benefits of the new system must be and have been identified.
- XII. Cost is an intrinsic component to many management decisions, a new model of the authoring process allowed the cost of producing a hypermedia application to be estimated. Yet, the process of estimating the cost can be a time consuming activity. However, the costing procedure can be simplified to allow a rough estimate of the effort by using heuristics, based on historical data gathered during the development of industrial hypermedia applications.

10.1.1 The Novel Research In This Thesis:

A new design methodology for designing large-scale industrial hypermedia applications was developed that encompasses the requirement and constraints of the industrial environment. As part of the design methodology a new authoring methodology was developed, using a new principle of Modular Hypermedia Applications (MHAs). MHAs enhance the portability, maintainability and scalability of the information system, and reduce the cognitive burden to the hypermedia author. A new method of providing an appropriate hypermedia user interface, has have a common look and feel yet allows the different group of users, with different abilities, access to the appropriate information, has been developed.

A new cost-effective evaluation methodology has been developed for evaluating industrial hypermedia. The evaluation has shown that hypermedia can be used effectively in an industrial environment. The users were able to find the information in about a third of the time, they had to visit fewer documents, they got lost less often, and preferred the hypermedia system to the current information system.

Some of the strategic considerations and benefits of introducing industrial hypermedia have been identified. In addition, a new methodology for costing the authoring process using historical data and heuristics, has been developed.

10.2 Future Work

10.2.1 Alternative User interfaces: - Virtual & Physical:

The concerns raised in the expert review about the supplying of information at the point of use and the ability to view all the information. The information is required at the point of use, for most office staff the point of use is the PC on their desk. However, for store people, factory-floor operators, or maintainer they need to be able to access the information away from an office desk. Portable computers are becoming lighter and radio communications becoming more effective [Siewiorek 98]. In addition, speech systems are becoming widely available and cheaper, possibly facilitating hands free navigation. In a paper-based system, a user may have opened in front of them a number of diagrams and books, in which they are able to glance from one to the other. However, they will only be reading one at a time. Hence, there needs to be some form of virtual 'bench top' in which

all the information can be laid out. Therefore, research is required on how to take the information to the point of use and that will present the user with the information they require, and into how this will effect the navigation paradigm.

10.2.2 Integration of a hypermedia system into the business process.

A manufacturing line and plant can have a life of over 30 years, however, computer systems and the software they run have a much shorter life. Any platform for which the hypermedia information system is developed will, in all probability become obsolete long before the plant. Hence, future systems need to be independent of the platform they run on. This in part can be achieved by the use of platform independent software like Java [SUN] and the Internet.

More companies are now using Internet browsers as interfaces to the document management system. This is partly due to the browsers having a common look and feel, and partly due to the fact that some users are already familiar with the interface. The major obstacle to the use of web browsers in industry was the inability to view technical drawings on the WWW. This has been overcome by commercial packages such as AutoCAD [Autodesk] which can display technical drawings in a WWW format and allows links to be made to the blocks, although limited to a single destination and much of the AutoCAD functionality is lost. In addition, the new XML [Moody 99] standards for defining links will enable the linking mechanisms currently used in the WWW to be extended. If this is then coupled with the distributed link service suggested by Carr et al [Carr 95] a very powerful platform independent system can arise.

There are a number of other emerging standards that may well facilitate the integration and acceptance of hypermedia into the industrial environment. The Open Hypermedia Protocol (OHP) [Davis 96] is a message-based protocol, which allows any viewer that is OHP compliant to communicate with any OHP compliant open hypermedia link service. Hence, the user does not need to have a viewer developed by the same company that developed the hypermedia system. This could enable OEMs to produce a hypermedia manual in one OHP compliant system and allow the user to view the information using any OHP compliant viewer produced by a different manufacturer.

In addition, the new standard for the Internet protocol (IPv6) will aid the security of transmitted documents, enabling verification of authenticity of revised electronic drawings. For example, the authorisation of electronic documentation is of great concern to manufacturing companies.

Even though many companies have advance CAD systems, they are still insistent on the 'wet ink principle' for a signature before a technical drawings is released. Yet, there is no technical or quality requirement for documents to be in a non-electronic format.

These emerging standards promise to simplify the implementation for industrial strength hypermedia and should remove some of the obstacles to a paper-less industrial environment. However, it is essential that the most appropriate solution be used for the application domain. Hence, further research is necessary to identify the 'drivers' and 'enablers' that will allow the business process to change to a paper-less environment and the effects these changes will have on the business processes.

10.2.3 Aiding general navigation by using taxonomy and text retrieval.

Computer generated links, Compute Links in Microcosm, can be used to access the key words in any text documents registered with the Microcosm system. Compute Links is a simple text retrieval system, which matches the word or phrase to a pre-indexed list. Compute Links will find all the occurrences of a word in the hypermedia application. Compute links are therefore a useful tool when authoring, in ensuring that all the explicit terms are linked together. Like the WWW it is possible with Compute Links to obtain numerous 'hits', most of which are not relevant to the search. By using a taxonomy of technical terms, searching the words around the query word, it should be possible at least, to rank the results. For example if the word 'resistance' is selected a query would select paragraphs that included subjects like: electrical resistance, resistance to change, heat resistance, wear resistance, etc. However, by checking the words around the key word, and using the taxonomy, the results can be ranked. The words around the Key word would not only check for engineering terms (technical and vernacular) but terms such as: similar to, unlike, not the same, confused with etc.

10.2.4 Tools to aid Navigation.

The structured expert reviews highlighted the need for tools to navigate the application. This is part of a wider issue of how the user navigates a large industrial application and associates nodes of information, again trying to brake the confines of the paper paradigm.

- In the industrial environment, large drawings are still dissected into small drawings. Hence, it is common for a maintainer to use several drawings in order to follow a signal through a circuit. In a hypermedia system, once the user reaches the edge of the one drawing they are required to click on the 'next drawing link' and wait for the system to fetch the next drawing. In order to save time, a system is required whereby the next drawing(s) are cached ready to be displayed if required.
- The initial hypermedia application will consist of the information and sets of links, these will endeavour to present paths through the information space. However, they cannot completely represent the paths that the users take. Therefore, a method of recording the user paths and publishing them is required. This would be useful for grouping the information used to solve a complex or common fault that occurs on a machine.
- The advantage of hypertext is its ability to allow the user to navigate unstructured text by association. Hence a tool is required to identify important, useful or pages of interest. These should allow both permanent and temporary identification of pages. Temporary identifiers could be used to identify interesting nodes while the user navigates the information resource. While permanent identification can be used to allow individualised short cuts and to create personalised clusters.

10.3 Concluding remarks

The programme of research has developed the strategy required for the implementation of a factory-wide hypermedia application. The emphasis being on the design and evaluation of large-scale industrial hypermedia applications, taking a holistic approach to the management and navigation of the growing information space in the industrial environment.

At present, the general interest in industrial hypermedia systems is cautious, as this technology is seen as 'new', although it has been commercially available for a number of years. However, this attitude is changing and the perceived risk associated with using

hypermedia technology is reducing, especially with the increase use of the World-Wide-Web, online documentation, and e-commerce.

Therefore, as the need for managing and navigating the information in an industrial environment increases, the demand for industrial hypermedia will be increase. Industrial hypermedia is not a panacea to all of industry's information management problems. It is, however, an effective weapon in the armoury for reducing information overload or information deprivation. While there is still an enormous amount of research to be undertaken in the field of industrial hypermedia, this research has endeavoured to resolve some of the fundamental issues facing the acceptance of hypermedia in industry.

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Appendix A.

Contextual Reviews.

Any developed hypermedia application should be relevant and specific to the application domain in which it is to be used. Therefore in order to produce an industrial application it is essential that the current work practices, and documentation structures, together with how they will effect the content the application should be clearly understood. Hence a detailed audit of the information structure and working practices was carried out on the Supertension Sheathing Line at Pirelli Cables, Eastleigh. In addition a shorter audit was carried out at the Ford Motor Company, Swaythling.

The method used to carryout the audit was the Contextual Inquiry method. Contextual Inquiry is a method that generally comes under the heading of interpretative evaluation. It is used in the collecting and analysing of data, on how people use technology in their natural situations i.e. the work place. Contextual Inquiry is less formal than many other methods of inquiry. The emphasis being on both the researchers and users participate in identifying and understanding usability problems within the normal working environment of the user. The items of interest for the researcher carrying out an interpretative evaluation are the: [Peerce 94]

- Structure and language used in the work.
- Individual and group actions and intentions.
- The culture affecting the work.
- Explicit and implicit aspects of the work.

Hence the investigation in one aspect of the industrial environment should not be carried out without reference to the wider work context. The rational behind this type of evaluation method is that the working environment and practical tasks required of the user will effect their behaviour. In addition the method emphasis that the interruption is of primary importance and not just the data. Hence, feedback to the user after each stage is important to ensure that the interpretation is correct.

Where the person writing the software is not familiar with the working environment, it is common practice to carry out the reviews with personnel from psychology or an expert in the field. This practice is to aid the author to understanding the working environment, uncover hidden work practices, spotting explicit and implicit work practices, etc. The author of this research has worked in maintenance, quality assurance and manufacturing environments.

Hence, personnel from psychology were not included in the contextual reviews. The contextual inquiry was carried out using a flexible interview approach to give a loose structure to the inquiry. A number of questions were asked of the QA department, Maintenance department, and factory-floor personnel. Where job functions crossed the same question was asked to each of the interviewees, in a manner appropriate to the job function. The purpose of the review was not to criticise or alter the working practice, but to examine how the hypermedia application would integrate with current practice and benefit the user on the factory floor. Both Pirelli and Ford operate a continuous improvement scheme and have BS EN ISO 9001 approval. In addition both companies prescribe to the Total Quality Management philosophy. This should ensure that all relevant information is available in a controlled manner. Below is a summary of the results of the inquiries, these were carried out between March 1996 and November 1997.

Documentation Control.

A1.1.1 Documentation Control at Pirelli Cables.

In Pirelli there are corporate wide procedures and divisional procedures, all of which apply to the Eastleigh site. The control of the documentation, is not centralised, with the Quality Assurance (QA) procedures and Technical Instructions (TIs) created and issued by the QA department, while COSH information and engineering drawings and data is controlled by the engineering department. While some technical specifications exist for in-house work, the main use of technical specifications dealing with workmanship specifications is for contractors. During the period of the review the Eastleigh site was intending to change the Quality documentation from a paper based control system to that of a factory wide computerised system to allow people to view any of the procedures, and with the correct permissions change them. However, it transpired that the intended use of the electronic QA documentation system was not possible due to licensing agreements. Hence, the new system has been introduced and limited to a few essential personnel, that is those who need to change the procedures. The method used for the remaining office staff is that the latest copy will be available for viewing only, on the virtual 'G' drive of their machine. Each 'drive' represents a domain see Figure A-1. Pirelli control the initial release and subsequent changes by the issue/reissue of a controlled copy. A red stamp and a unique serial number was used to identify the controlled copies. In addition the stamp identified if the document was an initial release or an amendment. Each procedure had a numbered distribution list, and a contents page showing the date of the last change. TIs are slightly different in that a single page can be changed. TIs were controlled by the date of each pages and not the document issue numbers. The change procedure was not a

closed loop system, it relied on the recipient to implement the change. Records of changes were kept for 10 years, and only hard (paper) copies of old revision levels/ change notes to procedures and TIs were stored.

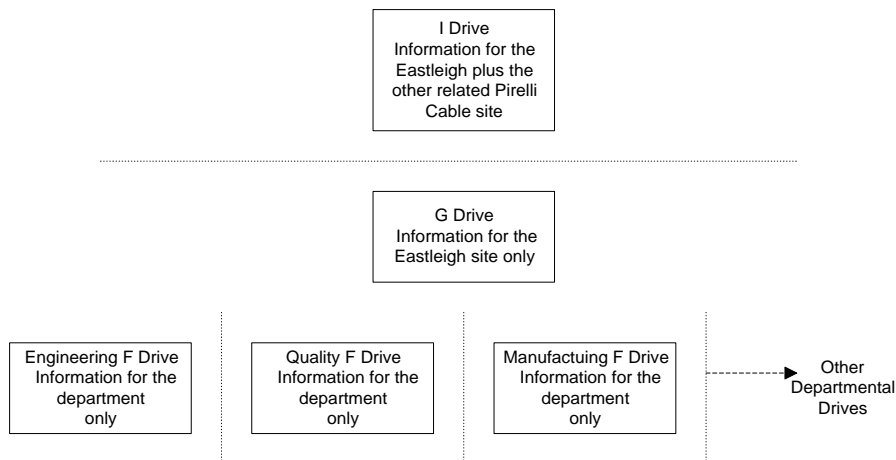


Figure A-1 Virtual Drive Allocation.

The rationale given by the Quality Manager for using a paper based system for the Quality Manuals was:

- Few people actually read the whole document regularly.
- Those who do read the document regularly often find it difficult to read on a screen, especially if the document was longer than a few screen lengths.
- There are often cross-references to other documents within the manual and with the present system it is difficult to view other on-line documents at the same time as the manual.

However, he could see the point of using the electronic version for infrequent users. The third party documents used in maintenance (drawings, manuals etc.) were not part of the documentation control procedure as the master copy were held in the Senior Preventative Maintenance Engineer's office with photo-copies on the shop-floor. Personnel can amend the copies of the third party documentation, that is the maintenance personnel amend the drawing after a modification, take a photocopy and pass it onto the drawing office. The documents were grouped; each group is identified with a letter that is the first character in the unique drawing number. The groups were E-electrical drawings, M-mechanical drawings, C-civil drawings and MAN-equipment manuals. Most drawings are copied onto microfilm, in the form of aperture card, very few of the original drawings were drawn using computer aided drafting (CAD).

A1.1.2 Documentation Control at Ford.

The Ford Car Company documentation system consists of 5 basic layers:

- The Company European Quality Manual. This only gave general statements and objectives.
- The Local Quality Manual. This stated whom was responsible and some broad statements on how to achieve the general statements above, included were the requirements of ISO 9000.
- The Company procedures. These are more detailed than the quality manuals. These were only issued to the department that were required to carry out the procedures, that is manger or supervisor level.
- Instruction Sheet. These consisted of single line instructions on how to carry out the operation.
- Forms/worksheets. These are used to record any data resulting from the above procedures.

As with Pirelli all master copies of documents at Ford had a red stamp. Hence, the stamp appeared as a black stamp on the photocopies. Updating of the documentation system was via circulation of the complete Manual or procedure after each amendment. The record of which department/section has a copy of the controlled procedure was held on a simple spreadsheet. Hence, only one person was required to oversee the documentation control procedure.

The number of procedure and their complexity has been reduced over the last couple of years, although they were continually being changed and reviewed. All of the documentation was now in electronic format and the quality manger at Ford was now looking to include it in an Information Retrieval System (IRS). The reason for not putting the information on an IRS before were:

- To reduce over a period of time the large number of procedures that were originally thought necessary, to those that were found to be working and fulfilled all the requirements.
- To ensure that staff were fully conversant with the system and how it operated, i.e. the staff only had to learn the system and not 'new' technology as well.

The Ford Quality Manager stressed that when installing a new system over 90% of the issues he faced, were people issues. The example given was Statistical Process Control (SPC), although the control charts could easily be produced by a Personal Computer, the shopfloor operators still produced and filled out the charts on paper, using a simple guide, the rational being that the shopfloor would then own the procedure.

A1.2 Supertension- Factory-floor operators.

The line operators at Pirelli Cables under go some basic training, then through a system of mentoring, progress from assistant operator to operator of the line. During training there was a training manual and technical instructions (TIs) to assistance the operators in learning how the

process line operates. After training the operators used little in the way of instruction sheets as most of the process sheets had been incorporated into a single spreadsheet. This spreadsheet was used to provide the operator with all the setting-up data they require.

The Control Of Substance Hazardous to Health (COSHH) sheets were held in the process owners office, in the vicinity of the line. The COSHH sheets were provided only for the materials used to manufacture the cables. The operators were made aware of the appropriate actions in the case of waste material. If there was a spillage of unfamiliar material or POL (paints, oils, lubricants), they were to call the shift supervisor, who in turn contacted the appropriate people.

TIs were held in the Process Owner's office in paper format and on the G hard drive. The operators do not normally refer to these and consequently were not readily available to the operator.

Pirelli were changing (albeit slowly) to a system of changing the skill level of the operators. In that the spreadsheet has set out precisely the initial/ideal setting required for setting-up the extruder. In addition, Pirelli cables were shortly to introduce a Gravitrol. The Gravitrol will ensure that the correct amount of material was extruded onto the cable core by measuring the insulation thickness (using lasers) and controlling the motor speed of the extruder. Hence, there was no longer the need for the operators to take measurements of the concentricity and set the motor speed accordingly. In addition the company will be moving from an informal continuous improvement scheme to one of Total Production Maintenance.

An in-house SCADA system called POMS (Production Operation Management System) will be introduced in late 1998 early 1999 into the Supertension manufacturing area. POMS systems were already in use in other manufacturing areas of the Eastleigh site and other Pirelli cable manufacturing sites around the world. This system will also allow the menu settings of a machine to be programmed off-line, for the user to simply download when required. This system was apparently first tried out at Pirelli Cables, Aberdare. In addition Pirelli will introduce some time in 1998 an IBM/SAP system on the factor-floor for data collection.

A1.3 Maintenance

At Pirelli Cables the Senior Preventative Maintenance Engineer (SPME) , see Figure A-2 ,has the responsibility for the maintenance on the Pirelli Cables Eastleigh site as a whole. The SPME was responsible for: -

- Maintenance Procedures.
- Stores.

- Calibration.
- Portable Appliance testing.
- COSH leaflets.

The SPME has been doing this job since 1987 and has refined the procedures, such that he personally can control the system. The maintenance software was written by IDhammer now Frontec and runs on an IBM AS 400 computer system. The SAP system will not, in the first instants, integrate with the IDhammer system.

Copies of the maintenance procedures were documented and held with the relevant QA procedures in the department, with the masters documents in SPME's office. The method for controlling and changing the maintenance procedures were a little vague. The reason being that the SPME personally carried out all the controlling and changing, and hence, there was little need for him to tell anyone else.

Responsibility for the maintenance of the Supertension process line was that of a dedicated Maintenance Engineer. The maintenance technicians for the Supertension line had a separate workshop to allow item to be removed and repaired.

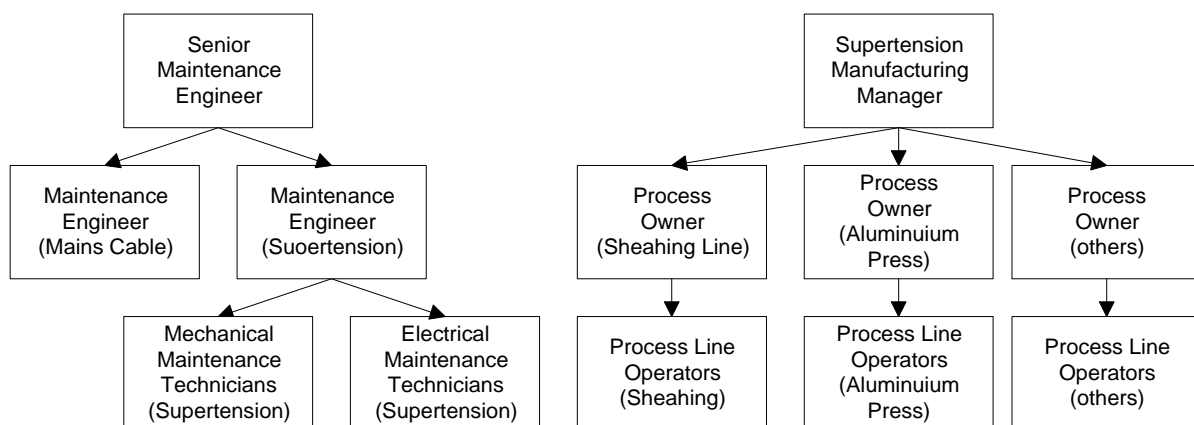


Figure A-2 Supertension Organisation Chart.

The maintenance technicians were trained by using a two-year program of specialist courses, most which were external and manufactures' courses tailored to the special needs of Pirelli (i.e. Siemens PLC and Eurotherm Drives). Due to the complex control systems, most personnel were educated to at least Higher National Certificate (HNC) level. Therefore, no general engineering training was given.

The Health and safety, COSH and company wide safety information was relayed to the maintenance personnel via folders in the workshop, with each sheet uniquely numbered. The procedures were controlled by the SPME going around and personally updating them. That is the data sheets arrived via the stores, post or with the equipment etc., these were then sent to the

chemist, who rewrites them into the company format. These then arrived at the SPME's desk, who then ensured that they were placed into the relevant folders in the maintenance workshops. Calibration was actual carried out by an engineer working for the SPME, who also held the record of calibration. Most calibration was carried out in-house, with the exception of some expensive specialist equipment that was externally calibrated and there was at least a duplicate at Eastleigh. Hence, there was no procedure for calibration of equipment, as there was an informal dialogue as to the timing of the calibration. The SPME identifies the equipment requiring portable appliance testing, while the Southern Electricity Board came in twice a year to carryout test on the required equipment. Therefore there was no procedure here either. Maintenance does not use calibrated tools. Calibrated tools were used only for the taking of measurements that were directly associated with the manufacture of the cable. While it was easy to understand the cost implications, the modern thought is that preventative maintenance does directly effect the quality of the product. No predictive maintenance was undertaken.

A1.3.1 Preventative Maintenance.

The preventative maintenance time table was calculated using a simple calendar principle which was based on mostly local knowledge, for frequency and length of the tasks, with a little guidance from the suppliers manuals. Metering of equipment was abandoned, as it was difficult to predict and plan to. It also had the disadvantages that a large number of pieces of equipment would had all require servicing at the same time.

General the information given to the technician to carry out the task was in the form of a Works Order. The Works Order, was a single sheet document that gave a brief description of the work to be undertaken and any specialist tools required. The piece of equipment were identified by a unique number AAA/BBBB/CCCC. Where AAA was the area (Supertension Cables was 200), BBBB was the line or centre (the Sheathing Line was 7000), and CCCC was the machine (the extruder was 4218).

One month prior to the preventive maintenance being carried out, a list was placed in each area. This enable the line operators to write down what other items needed repairing or servicing during the preventative maintenance, if the Process owner agrees the extra resources and necessarily equipment were allocated and piece parts ordered.

The Supertension manufacturing line as a whole was programmed to run continually, that was 24 hours a day 7 days a week. Preventative maintenance was continually take place throughout the

week when the machines were not carrying out a process, for example between production runs when the machine was being set-up.

On the main sections of the Supertension Line, the skilled maintenance personnel received a number of sheets every time maintenance was required. This consisted of a list of tasks to perform and a short yet descriptive paragraph of what to inspect and other information found to be useful by the maintainer. The information included such details as the ideal length of the motor brushes and their tolerance, voltages and current ranges, etc. The maintenance technicians also used the sheets to sign to signify that the work had been completed and record any faults they found. The method used can be quite complex. For example, the reminder from the SPME would be passed to Maintenance Engineer with the work sheets, who would then fill out the forms and raise work orders. These would then be passed to the personnel to carry out the work. The personnel would have to carry around the stack of paperwork signing off each job and recording any faults. On completion, these would go back to Maintenance Engineer for checking and then onto the SPME.

B1.3.1.1 The Supertension Sheathing line

Preventative maintenance to the Sheathing Line was carried out every 26 weeks. On the Supertension Sheathing line, there was little information for preventive maintenance other than a simple one line instruction checklist. In addition the manuals from Nokia-Maillefer and other Original Equipment Manufactures (OEMs) were available in the workshop. The reason for the lack of information was in part due the line being recently installed and in part due to a change in policy.

Gone was the stack of pages for each item on the Sheathing Line planned maintenance schedule. As the general system described above was deemed by the Maintenance Engineer to be over burdening with an enormous amount of superfluous paperwork and did not respect the ability of the maintainers.

Hence, the refinement of the system for the Supertension Sheathing line was carried out. On receipt of a memo from SPME informing the maintenance technician which machines were to be serviced, the maintainer would themselves raises a simple one sided A4 form and collect the manual. The Manual consisted of only 2 pages of one-line instructions for electrical and 3 pages of one-line instructions for mechanical personnel.

If any faults were found during the maintenance program, they were recorded on the front sheet. If no outstanding faults remained, the form was filed and the manual put back into the rack. If

the faults were not fixed during the maintenance period, the manual with the form in the front was left out for the Maintenance Engineer to action when they next comes into work.

It may seem to be a drastic cut, yet the system was working effectively, in that few breakdowns occur. The system does not however close the loop or monitor faults well. The list uses the word '*check*' (physically inspect) in all the instructions, yet often only an examination (visually inspect) was required. Also there was no information as to what to check against for example, how long and to what tolerance. It may seem pedantic in the choice of words such as check, examine and re-fit, however experience of safety systems has shown clear instruction and hence the choice of words (with a clearly defined meaning) was of benefit to everyone.

There were some weekly checks of the currents for the extruder equipment. The reason being that the current would rise if faults start to occur. Again this was a simple form to be filled out, the maintainer check the results against the list of reference currents.

A1.3.2 *Corrective Maintenance.*

Operators were able to request corrective maintenance by contacting maintenance directly.

There were two forms for recording requests for maintenance. One form was to record faults that had caused a breakdown. The other form was used to record non-breakdown requests for maintenance. The forms were place centrally in the Supertension process line.

In each area of the Supertension process line, there was a list of machine priorities. Machines marked Priority were served first, then those marked constraint, then normal. This information was displayed on a large board in each area and could change daily. Once the fault was repaired the maintainer was to add comments, (in practice this rarely happens). Very little information was given to the maintainer to fix the faults, a lot depended on their ability and memory of pervious faults. This was not a problem as Pirelli only employ highly skill trades people (HNC or with equivalent experience) that work in a particular area. The maintainers move around a little, to cover a shortage in personnel, it was at this point that most maintainers would refer to a manual or diagram.

If piece parts were required for corrective maintenance that stop production a works order was raised in order to obtain piece parts, as the information needed to be passed back to head office in Italy.

A1.3.3 *Material for Maintenance.*

The material required to carry out the maintenance task were not available in advance. The rational was that items may not need replacing. For example, a belt should last a minimum of 3 months, but when the fitter examined it, they saw that it will last for the next 3 months, hence

they did not replace it. The stores carried a range of items likely to be needed for preventive/corrective maintenance. For preventative maintenance, and corrective maintenance that did not stop production, these items were requested by the maintenance personnel using a small form, and a simple order number, that consisted of the line number and year (i.e. sheathing line works order number was 70001997). In addition, the maintenance personnel were able to request that items be placed on order without the Maintenance Engineer being there.

In practice the maintenance technician would identify and requisition the spare piece parts by taking the item in question to stores, obtains the replacement part, the fitter then confirms that the item was what they wanted. At this point, the data was entered onto the stores computerised system, and the stock levels adjusted.

A short evaluation of the IDhammer system, showed it to be a fixed screen text based system. In the opinion of the operators, engineers and managers, this was awkward to use. For example to find a part number the user typed in the area, line, and equipment number, from this the user obtained a list of piece parts. The user noted the Pirelli part number, then went to another screen typed in the part number to find out if any were in stock. Only short descriptions were available on the first screen. Hence, if more than one item had the same name, the users had to record the part number then go to another screen to find a complete description typing in one number at a time.

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Appendix B

Fault Codes

Code	Description	Action Required	Reference Documents
1	Take-up caterpuller's motor stall trip detected	<ol style="list-style-type: none"> 1. Mechanical Check of Caterpuller. 2. Check field current trip not active. 	Eurotherm 590 Manual Chapter 16 Alarms Take-up Caterpuller Eurotherm DC Cabinet Wiring Line Control Unit
2	Under temperature on Bitumen tank zone 4	<ol style="list-style-type: none"> 1. Check that the heating element is connected correctly 2. Check fuse has not blown on heating element 3. Check that the heating element supply has not be come disconnected 4. Check that the heating element is operating correctly 5. Check Thermocouple is located correctly 	E000003906 Schematic Diagram For Trace Heating: heating zone 1-6 E000003910 Schematic Diagram For Trace Heating: thermocouple zone 4-6
3	The pay-off caterpuller will not jog forward	<ol style="list-style-type: none"> 1. Check that it will jog backwards (to the RIGHT). 2. Check Supply to relay contacts 3. Check jog forward relay 4. Check input to Line Control Unit. 	Unit Structure Eurotherm DC-drive Cabinet Drawings 751466 Line Control Unit Lubrication and Maintenance
4	Compressed air system is not working	<ol style="list-style-type: none"> 1. Ensure power available. 2. Check: power on terminal rail 	Training manual Line Control Unit
5	Under temperature on extruding Crosshead	<ol style="list-style-type: none"> 1. Check that the thermocouple is connected correctly 2. Check that the heating element is operating correctly 3. Check that the supply to the temperature controller has not be come disconnected 4. Check that the thermocouple is located correctly 	Crosshead manual Extruder manual Crosshead Connection box. Temperature Controller.
6	Under temperature on Extruding Zone 1	<ol style="list-style-type: none"> 1. Check that the thermocouple is connected correctly. 2. Check that the heating element is operating correctly 3. Check that the supply to the temperature controller has not be come disconnected 4. Check that the thermocouple is located correctly 	Extruder manual Extruder Electrical Connection manual Line Control Unit. Temperature Controller.
7	Extruder Feeding Assembly Filter is Blocked	Replace Filter.	Extruder manual Extruder Operating manual

8 M	Over temperature on Bitumen tank zone 2.	<ol style="list-style-type: none"> 1. Check that the heating element is operating correctly. 2. Check supply to the temperature controller. 3. Check thermocouple is located correctly. 	E000003906 Schematic Diagram For Trace Heating: heating zone 1-6. E000003909 Schematic Diagram For Trace Heating: thermocouple zone 1-3.
9 M	Under temperature on Cleaning Station thermocouple 1	<ol style="list-style-type: none"> 1. Check that the heating element is connected correctly 2. Check fuse has not blown on heating element 3. Check that the supply to temperature controller has not become disconnected 4. Check that the heating element is operating correctly 5. Check thermocouple is located correctly. 	Cleaning Station. Temperature Controller
10 M	Over temperature on Cleaning Station thermocouple 1	<ol style="list-style-type: none"> 1. Check thermocouple is located correctly. 2. Check that the heating element is connected correctly <p>Check that the temperature controller is operating correctly.</p>	Cleaning Station. Temperature Controller.
11 M	Under temperature on Cleaning Station thermocouple 2	<ol style="list-style-type: none"> 1. Check that the heating element is connected correctly 2. Check fuse has not blown on heating element 3. Check that the supply to temperature controller has not become disconnected 4. Check that the heating element is operating correctly <p>Check thermocouple is located correctly.</p>	Cleaning Station. Temperature Controller.
12 M	Over temperature on Cleaning Station thermocouple 2	<ol style="list-style-type: none"> 1. Check that the heating element is connected correctly 2. Check that the supply to temperature controller 3. Check that the heating element is operating correctly <p>Check thermocouple is located correctly.</p>	Cleaning Station. Temperature Controller.

M= Actual Faults monitored by the simulation system.

Table B-1 Fault code information.

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Appendix C.

HAMAS Evaluation

C1. Criteria

The criteria in full, from the paper [Christodoulou 98], to assess a Hypermedia Application Development and Management System (HADMS) are:

A. Common Criteria among the Three First Steps

- A1. *Structural constraints.* The methodology must support the definition and maintenance of structural constraints (e.g. composites that may not contain themselves recursively) and guarantee their enforcement among hypermedia objects participating in any of the three design steps.
- A2. *Design evolution.* In order to provide extensibility and tailorability it is required that design evolution is supported, in each of the three first basic steps, with automatic propagation of the modifications from the step (design model) where they occur, to the other steps. The design evolution should cover the fundamental requirements for a hypermedia development environment that Nanard and Nanard have identified in [Nanard 95]
- A3. *Reusing and tailoring.* This refers to the ability to allow reusing and tailoring of application-specific types of objects among different applications.

B. Conceptual Data Model Design

- B1. *Basic hypermedia support,* The data model approach used to map application objects to hypermedia objects should provide at least a set of basic types for hypermedia objects such as nodes, links, anchors, etc.
- B2. *Multimedia support,* of existing multimedia types and ability to integrate future ones.

C. Abstract Navigational Model Design

The criteria in this category are further categorised into Node, Link and Navigational Features.

Node Features:

- C1. *Semantically typed nodes* categorise a node's contents, help authors organise information more effectively and lend context to readers.
- C2. *Composites* Dealing with groups of links and nodes..

Link Features:

C3. Semantically typed links. Information contained by a link type can be a user-interface level action triggered by a user following the link or the resource the link points to or the way two, or more, nodes are related, such as "explanation".

C4. Link attributes. In addition to types, other semantics can be attached to links, such as labels, names, keywords or timestamps. Smarter links could contain other information like abstracts and sizes of the linked-to files that would aid a user in his selection.

C5. Bi-directional links. This refers to the ability of the system to support links that can be accessed from either endpoint.

C6. Anchors embedded in node content: Ability to include either the start or end-point of a link inside the content of a node.

C7 Internal link update mechanisms, guaranteeing consistency (avoiding broken links). Whenever a node is removed, every internal link of the application pointing to it should be removed.

C8. Automatic creation of links among nodes, according to their contents and types.

While most links are handcrafted, the larger the information base, the less feasible authors find it to compose all links manually.

Navigation Features:

C9. Global and local views, improve spatial context and reduce disorientation in a hypermedia network]. *Global views* provide an over-all picture and can also provide entry points for local views. *Local views* provide a detailed view of the local neighbourhood of a node.

C10. Node and link participation in different views. Support of different behaviour for hypermedia objects, since many hypermedia applications support multiple uses of hypermedia objects in different contexts.

C11. Access structures. This refers to the ability to create structural parts of a hypermedia application (summary objects), e.g. menus, indexes, guided tours, indexed guided tours.

C 12. Personalization features (user profiling). Such features are the *Path-tracking* and *Adaptive Navigation Support*. A reader's path (documents a reader's earlier visited) could be saved and restored on reader's demand. A path can be used to collect all interesting documents to form a linear document that can be preserved in printed form or to help developers find the more frequently visited paths and to avoid readers to revisit the same information units. *Adaptive Navigation Support* controls which links and their corresponding properties should be activated based on the user's previous interactions. Hypermedia

applications should include filtering mechanisms to present only the most relevant links, based on the users' current goals.

D. User-Interface & Run-time Behaviour Design.

D1. How interface objects map to navigational objects. The design approach for describing the user interface of an application.

D2. Specification of run-time behavior to interface objects. Specification of the reaction of interface objects to external events.

D3. Synchronization of interface objects, particularly when dynamic media such as audio and video are involved.

D4. User-defined instantiation. The environment should allow a reader to create different views from the same semantic hypertext and give the readers the chance to choose the way they prefer to see the information, including jumping from view to view. The readers should be able to issue commands to the hypermedia application that will allow the traversal of information in their own personal manner.

E. Implementation issues

E1. Dynamic content. Ability to generate and/or display content at run time, dynamically generated from the storage model of the system.

E2. External storage systems. Ability to integrate or cooperate with external storage systems, from RDBMSs and OODBMSs to video servers, document management systems, knowledge bases or GISs.

E3. Simplicity. Ease of using the methodology for designing and implementing an application.

Environment Evaluation Criteria

This category includes criteria used for the evaluation of the implementation environments of HADMS. These criteria concern the support for the implementation, testing and maintenance stages of the application life cycle.

F. General

This category introduces various kinds of evaluation criteria requiring from the environment to provide capabilities like distribution, extensibility and information retrieval.

F1. Client/server distribution. The ability of the environment to be based on a client/server architecture, allowing its users to have remote access to it through the network.

F2. External tools. The ability to integrate external tools (e.g. text or HTML editors, media processing tools) into the environment.

- F3. Extensibility* (Scripting capabilities /API). Flexibility for the developer to enhance existing or add new features to the current implementation.
- F4. Importing*. Support of batch information importing from databases, filesystems, WWW sites (locally or over network through HTTP), etc. The system should also provide extensibility to the supported formats.
- F5. Content-based information retrieval mechanisms*. The application developer should have the ability of content-based search on the content of the application.
- F6. Structure-based information retrieval mechanisms*. In addition to a text string search facility for node content, structure-based queries based on node and link attributes are often useful. An example of such a query is "find the abstracts of all technical reports modified during the previous month".
- F7. Supporting utilities*, such as find & replace expressions in the application content, spell checking, etc.
- F8. Quality testing*. How much does the environment assist users in evaluating their application design.

G. Collaborative work

In order to serve an organisation's working groups, hypermedia development methodology features have to coexist with collaborative features that enable people to work together during the design, development and maintenance phases. Collaborative tools maintain many relationships between a working group's members, tasks, and information.

- G1. Simultaneous multi-user access*, including robust concurrency control mechanisms. Allow multiple users to access concurrently the development environment while preserving the consistency and integrity of data.
- G2. Access control*. Besides standard read and write access permissions on documents, system administrators may consider analogous read and write permissions for hypermedia objects. For certain documents one could allow link authoring and update while prohibiting write access to the underlying content. Access permissions may prove most useful for allowing individuals to maintain a personal set of nodes, links and annotations, while collaborating workgroups maintain shared sets of objects.
- G3. Member activity tracking*. Tracking actions and/ or modifications made by each member of a team.
- G4. Notification controls*. Users can be informed about modifications that have taken place on contents or structures.

G5. Versioning at the level of individual entities e.g. links, nodes and also at the level of the hypermedia application schema. Version control provides one way to control the disruptive effects of change without the worse solution of preventing or obstructing it.

G6. Annotations (private, workgroup or public). Creation of annotations (comments) is a basic right for hypermedia readers as well as a basic tool for collaboration and exchange of ideas. The environment should support private, workgroup or public annotations, providing them to any person who has the appropriate access permissions.

G7. Interactive collaboration: Support of audio and video teleconferencing and interactive electronic whiteboards.

H. User Interface (UI). - Friendliness and ease of use. This category includes criteria relative to the friendliness of the environment's UI and the ease of using it.

H1. *UI of the design and implementation environment*, which is used by designers and implementers during the basic methodology steps.

H2. UI of the authoring environment, used by authors to insert, update or delete information.

H3. *Intelligent user assistance*, e.g. wizards, functional on-line help etc.

The methodologies criteria are A-E and the Environment criteria are F to H.

	Industrial Requirements	FIRM	OOOHDM	RMM	HSDL	HSM	Strudel	Story	FP
A1	3	3	2	2	2	3	1	1	1
A2.	2	2	2	2	2	2	1	1	1
A3.	3	3	3	1	1	3	1	3	1
B1.	3	3	3	3	3	3	3	3	1
B2.	3	3	2	1	0	3	1	2	1
C1.	1	1	1	1	1	1	1	1	0
C2.	2	2	2	2	2	2	1	1	0
C3.	3	3	3	1	2	3	1	1	0
C4.	3	3	3	0	0	3	0	0	0
C5.	1	1	1	1	1	1	1	0	1
C6.	3	3	3	0	3	0	1	0	2
C7	3	3	2	2	3	2	2	1	3
C8.	3	3	0	0	0	1	0	0	0
C9.	3	3	3	1	3	0	1	0	2
C10.	3	3	3	2	3	3	3	0	0
C11.	3	3	2	3	2	0	2	2	1
C12.	2	2	1	0	1	1	0	2	1
D1.	0	0	0	0	0	0	0	0	0
D2.	3	3	3	0	0	0	0	2	1
D3.	1	1	1	0	0	1	0	0	1
D4.	2	2	2	0	0	0	0	2	0
E1.	0	0	0	0	0	0	0	0	0
E2.	3	3	0	0	0	2	1	2	1
E3.	3	3	1	2	2	1	1	3	3
Methodology	56	56	43	24	31	35	22	27	
Normalised	1	1	0.768	0.428	0.554	0.625	0.393	0.482	0.375
F1.	0	0	0	0	0	0	0	0	0
F2.	3	3	0	2	1	2	0	3	3
F3.	3	3	0	2	2	3	0	3	0
F4.	3	3	0	0	2	0	0	3	1
F5.	3	3	0	0	0	2	0	2	2
F6.	1	1	0	0	0	1	0	0	0
F7.	0	0	0	0	0	0	0	0	0
F8.	0	0	0	0	0	0	0	0	0
G1.	0	0	0	0	0	0	0	0	0
G2.	0	0	0	0	0	0	0	0	0
G3.	0	0	0	0	0	0	0	3	0
G4.	1	1	0	0	0	0	0	1	0
G5.	3	3	0	0	1	0	0	2	2
G6.	1	1	0	0	0	0	0	1	1
G7.	0	0	0	0	0	0	0	0	0
H1.,	3	3	0	2	3	1	0	3	0
H2.	3	3	0	1	2	1	0	2	3
H3.	3	3	0	0	1	0	0	2	3
Environment	27	27	0	7	12	10	0	25	15
Normalised.	1	1	0.000	0.259	0.444	0.370	0.000	0.926	0.556
Overall	83	83	43	31	43	45	22	52	36
Normalised	1	1	0.518	0.373	0.518	0.542	0.265	0.627	0.434

Table C-1 The rating of each HADMAS against the requirements of an industrial application.

C2. OVERVIEW OF HADMS Used In The Evaluation

The paper by Christodoulou et al [Christodoulou 98], also included some HADMS that explicitly for web based system and embbed links. To provide a fuller understanding the author has copied abstracts from the section of the paper that provided an overview of the HADMS used.

HSDL

The Object-oriented (OO) approaches OOHDM and HSDL were selected as representatives for this approach (HSDL was selected additionally because OOHDM does not provide an environment).

The HSDL (Hypertext Structure Description Language) is a visual hypermedia-authoring environment, which uses the Structure Description Language as the base for the persistent data model storage mechanism. The core of the environment is the *schema* that consists of an intentional description, the *class schema*, and an extensional description, the *instance schema*. The class schema consists of classes and link-classes between them. The instance schema consists of instances and link instances. Large hypertexts are often organized as *hierarchies*. The HSDL implementation enforces strict referential integrity on the class and on the instance schemas. In HSDL several *schema evolution* operations are supported, such as reposition of a component in a class, split a class into two new classes, etc. The *translation* of a schema into HTML is controlled by a series of programs, called *expanders*.

Story

Other HADMS adopt component-based approaches, in which the content of the application is hierarchically decomposed into components. A component is defined by its state (which is specified by a list of properties) and its behavior (operations on component states).

Components can be derived from other components based on a prototype-instance model, which is simpler than the OO model.

StoryServer is a commercial product, developed by Vignette. It has a component-based architecture, which treats the functional elements of the Web site (content, format, application logic) as individual components, which can be built, managed and reused independently.

StoryServer integrates a Web content management system with a content application server.

The content management system creates a collaborative workflow environment for controlling the production and delivery content, while the content application server dynamically combines content with business processes and customer interaction to deliver personalised site viewing. It supports Adaptive Navigation, which personalises the site navigation structure based on users preferences and their context depending on the way they navigate the site. Another element of StoryServer is the Production Centre, a Java-based

client application that facilitates the collaboration among all members of the development team - managers, designers, content creators, authors and administrators.

STRUDEL

Some other HADMS follow hybrid approaches. Such approaches integrate data from various heterogeneous sources. Thus, they can accommodate data in various models without requiring storage of all data in one given repository. Such approaches include STRUDEL. STRUDEL provides a single graph model in which different data sources (e.g. existing Web sites and various types of external databases) are uniformly modelled. It allows users to manipulate the underlying data independently of where it is stored or how it is presented and to customize the web site by creating different views of the underlying data. Defining sites as views over the integrated data requires a single query language whose results are Web sites in the form of graphs of HTML pages. STRUDEL provides a query language for both data integration and view definition. However, STRUDEL cannot be used for managing the underlying data (it is an effective solution mostly for read-only sources equipped with their own management interface).

HSM (HyperStorM)

HyperStorM proposes an extensible OO hypermedia system, which supports the specification of application semantics as application classes within the hypermedia system, thereby supporting complex operations maintaining application-specific as well as application-independent constraints. In the HyperStorM hypermedia system, the storage layer and the application layer of a hypermedia system are implemented within the OO database management system VODAK. This approach facilitates both the reuse of database functionality and the support of the development of different kinds of hypermedia applications, but only for this hypermedia system.

FP

Front Page is a commercial product developed by Microsoft design to aid users to simply develop and administer Web sites. Front page uses a graphical user interface, incorporating a HTML editor and wizards for embedded scripting languages and applets.

It provides support tools such as the automatic update of links, detection of broken links, editors, style sheets, form creation, collaborative authoring and security.

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Appendix D.

The List of Questions used in the User Questionnaires.

Questionnaire: - User Opinion After Training

Impression - the users feelings or emotions when using the software.				
1. The system is one that I would want to use on a regular basis.	Strongly Agree	Agree	Disagree	Strongly Disagree
2. The system was very demanding and not enjoyable to use.	Strongly Agree	Agree	Disagree	Strongly Disagree
3. This high-tech route to information is intimidating	Strongly Disagree	Disagree	Agree	Strongly Agree
4. The system was frustrating to use.	Always	Most of the time	Some of the time	rarely
5. I would recommend this system to my colleagues.	Strongly Agree	Agree	Disagree	Strongly Disagree
6. I enjoyed working with this system.	Always	Most of the time	Some of the time	rarely
7. This system was really very awkward to use.	Always	Most of the time	Some of the time	rarely
Command - the measure to which the user feels that they are in control.				
8. The system was responsive to my inputs	Always	Most of the time	Some of the time	rarely
9. I did not find it easy to start the application	Strongly Agree	Agree	Disagree	Strongly Disagree
10. I felt I had no control over the system	Strongly Disagree	Disagree	Agree	Strongly Agree
11. The system did not respond quick enough to my selections	Strongly Disagree	Disagree	Agree	Strongly Agree
12. If the system stopped working it was not easy to restart it.	Strongly Agree	Agree	Disagree	It did not stop
13. It was easy to make the system do exactly as I wanted.	rarely	Some of the time	Most of the time	Always
Effectiveness - the degree to which the user feels that they can complete the task while using the system.				
14. To get to the information I needed was straight forward.	Always	Most of the time	Some of the time	rarely
15. Using the system hindered the task I was undertaking	Strongly Agree	Agree	Disagree	Strongly Disagree
16. I was not able to find the information I required	Always	Most of the time	Some of the time	rarely
17. There are too many steps required to get to the information.	Strongly Disagree	Disagree	Agree	Strongly Agree
Navigability - The degree to which the user can move around the application.				
18. It was easy to move around the information.	Strongly Agree	Agree	Disagree	Strongly Disagree
19. There were plenty of ways to find the information I needed.	Strongly Disagree	Disagree	Agree	Strongly Agree
20. The toolbar provided useful short cuts.	Strongly Agree	Agree	Disagree	Strongly Disagree

21. I could find my around the information using the menus and content pages.	Always	Most of the time	Some of the time	rarely
22. It is easy to become disoriented when using the system	Strongly Agree	Agree	Disagree	Strongly Disagree
23. I Knew where to go next with the system.	rarely	Some of the time	Most of the time	Always
Learnability - the degree to which the user feels that the application is easy to become familiar with.				
24. I felt safer when using only the method I was familiar with to find the information.	Strongly Agree	Agree	Disagree	Strongly Disagree
25. The guidance given before using the system, was enough to use the system	Strongly Disagree	Disagree	Agree	Strongly Agree
26. I felt safe trying different ways to get to the information.	Strongly Agree	Agree	Disagree	Strongly Disagree
27. Learning to use the system was easy.	Very Easy	Easy	Not so easy	difficult
Aidability - the degree to which the application assists the user to resolve a situation.				
28. The system was helpful in coping with the error	Always	Most of the time	Some of the time	rarely
29. The system help files provide enough information	Strongly Disagree	Disagree	Agree	Strongly Agree
30. I was unsure if I was using the right command.	Always	Most of the time	Some of the time	rarely
31. There was not enough information displayed on how to respond/proceed.	Always	Most of the time	Some of the time	rarely
32. I found the system awkward to use if I wanted to do something out of the ordinary	Strongly Disagree	Disagree	Agree	Strongly Agree
33. I could not understand or act on the information provided by this system.	Strongly Disagree	Disagree	Agree	Strongly Agree
Comprehension: - The degree to which the user understood the interaction with the application.				
34. The information was clearly presented and understandable.	Strongly Agree	Agree	Disagree	Strongly Disagree
35. The information displayed was inconsistent.	Strongly Agree	Agree	Disagree	Strongly Disagree
36. The actions associated with the buttons on the main toolbar were easily understood.	Strongly Disagree	Disagree	Agree	Strongly Agree
37. The screens became cluttered and confusing	Strongly Disagree	Disagree	Agree	Strongly Agree
38. I understood the action of the window's tools bars.	Always	Most of the time	Some of the time	rarely
39. I understood how to operate the system.	Always	Most of the time	Some of the time	rarely
40. To get to the relevant information I had to scroll down the page	Always	Most of the time	Some of the time	rarely
41. The layout of the manuals was satisfactory	Strongly Agree	Agree	Disagree	Strongly Disagree
42. The buttons were clearly visible in drawings.	Strongly Agree	Agree	Disagree	Strongly Disagree
43. Too much text was displayed at any one time	Strongly Disagree	Disagree	Agree	Strongly Agree

Questionnaire: - User Opinion After Time Trials.

Impression- <i>the users feelings or emotions when using the software.</i>				
44. I prefer to use the paper based system regular	Strongly Agree	Agree	Disagree	Strongly Disagree
45. This high-tech route to information is intimidating.	Strongly Agree	Agree	Disagree	Strongly Disagree
46. The Computer-based system was frustrating to use.	Strongly Agree	Agree	Disagree	Strongly Disagree
47. I found the Paper-based system was awkward to use.	Strongly Agree	Agree	Disagree	Strongly Disagree
48. The Computer-based system is one that I would want to use on a regularly basis	Strongly Agree	Agree	Disagree	Strongly Disagree
49. I enjoyed working with the computer based system	Strongly Agree	Agree	Disagree	Strongly Disagree
50. I would recommend the computer-based system to my colleagues	Strongly Agree	Agree	Disagree	Strongly Disagree
Command - <i>the measure to which the user feels that they are in control.</i>				
51. It was able to make the computer-based system do exactly as I wanted.	Strongly Agree	Agree	Disagree	Strongly Disagree
52. The computer-based system did not react quick enough to my selections	Always	Often	Some of the time	Never
53. I did not have complete control over the system	Strongly Agree	Agree	Disagree	Strongly Disagree
54. The system was responsive to my inputs	Strongly Agree	Agree	Disagree	Strongly Disagree
Effectiveness - <i>the degree to which the user feels that they can complete the task while using the system.</i>				
55. To get to the information I needed in the PAPER -based system was straightforward.	Strongly Agree	Agree	Disagree	Strongly Disagree
56. In the PAPER-based system I had to go though many steps to get to the information	Strongly Agree	Agree	Disagree	Strongly Disagree
57. Using the PAPER -based system hindered the task I was undertaking	Strongly Agree	Agree	Disagree	Strongly Disagree
58. When using the PAPER-base system I found it difficult to obtain the information I needed.	Strongly Agree	Agree	Disagree	Strongly Disagree
59. In the COMPUTER-based system there are too many steps required to get to the information	Strongly Agree	Agree	Disagree	Strongly Disagree
60. In the COMPUTER based system I found it straightforward to get to the information.	Strongly Agree	Agree	Disagree	Strongly Disagree
61. Using the COMPUTER -based would get in the way of the task I was undertaking	Strongly Agree	Agree	Disagree	Strongly Disagree
62. When using the COMPUTER -base system I found it difficult to obtain the information I needed.	Strongly Agree	Agree	Disagree	Strongly Disagree
Navigability - <i>The degree to which the user can move around the application.</i>				
63. I frequently did not know where to go next with the paper-based system.	Strongly Agree	Agree	Disagree	Strongly Disagree
64. I was able to move around the computer-based information easily	Strongly Agree	Agree	Disagree	Strongly Disagree
65. The computer-based toolbar provided useful short cuts.	Strongly Agree	Agree	Disagree	Strongly Disagree
66. I did not find the computer-based menus and content pages useful.	Strongly Agree	Agree	Disagree	Strongly Disagree
67. I often become lost/disoriented when using the computer-based system	Strongly Agree	Agree	Disagree	Strongly Disagree
68. There were plenty of ways to find the information I needed.	Strongly Agree	Agree	Disagree	Strongly Disagree

Learnability - the degree to which the user feels that the application is easy to become familiar with.				
69. Learning to use the system was easy.	Strongly Agree	Agree	Disagree	Strongly Disagree
70. I felt safer when using only the method I was familiar with to find the information.	Always	Often	Some of the time	Never
71. The guidance given before using the system, was enough to use the system	Strongly Agree	Agree	Disagree	Strongly Disagree
72. I felt safe trying different ways to get to the information.	Strongly Agree	Agree	Disagree	Strongly Disagree
Aidability - the degree to which the application assists the user to resolve a situation.				
73. The system messages were helpful in coping with the error	Always	Often	Some of the time	Never
74. I understood and was able to act on the messages provided by this system.	Always	Often	Some of the time	Never
75. The system was awkward to use if I wanted to do something out of the ordinary	Strongly Agree	Agree	Disagree	Strongly Disagree
76. I was unsure if I was using the right command.	Always	Often	Some of the time	Never
77. The system help files provided enough information.	Strongly Agree	Agree	Disagree	Strongly Disagree
78. There was not enough information displayed on how to respond/proceed.	Strongly Agree	Agree	Disagree	Strongly Disagree
Comprehension: - The degree to which the user understood the interaction with the application.				
79. The actions associated with the buttons on the main toolbar were easily understood.	Strongly Agree	Agree	Disagree	Strongly Disagree
80. I did not understand the action of the window's tools bars.	Strongly Agree	Agree	Disagree	Strongly Disagree
81. I understood how to operate the system.	Strongly Agree	Agree	Disagree	Strongly Disagree
82. The information was clearly presented and understandable.	Always	Often	Some of the time	Never
83. The information displayed was inconsistent.	Always	Often	Some of the time	Never
84. The layout of the manuals was satisfactory	Always	Often	Some of the time	Never
85. The buttons were clearly visible in drawings.	Always	Often	Some of the time	Never
86. Too much text was displayed at any one time	Always	Often	Some of the time	Never
87. To get to the relevant information I had to scroll down the page	Always	Often	Some of the time	Never
88. The screens became cluttered and confusing	Always	Often	Some of the time	Never

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Appendix E. Comments by expert reviewers for HCI Expert Review.

Group 1, Dr David B Lowe and Dr Steve Rake.

Scenario 1 : Setting up of the cable Laying on machine R2.

1. The screen text is not clear (incomplete, not sharp) due to the screen resolution.
2. The button Hide Microcosm Filters, is this necessary for the operator, should they know about filters? This may cause confusion in that the operators may think they should know about filters and may worry that they have missed something important.
3. When using the graphical interface the users could not always follow a button link and several goes were required before the system actioned the request.
4. The expert users found that they could get to the information quicker by using the select a document window than the graphical interface.
5. On the page on laying, the following was observed.
 - A number of typing errors in the text made it confusing.
 - The text only referred to what had to be done and not how and why. For example adjust the speed (no other information is given as to, by how much and in which direction).
6. The photograph had a confusing title 'Laying bitmap (466)', Again the operator may find the word 'bitmap' confusing.
7. Photograph can be annotated with helpful information.
8. With the video, it failed to complete the sequence the first time and auto shut down at the end on the other attempts to view it.
9. The video window did not register as being open on the toolbar.
10. Poor (nondescript) titles generally on video, pictures and text boxes.
11. The pages of text are automatically maximum size on selection, although you can change the size for viewing, when next selected they will revert to maximum size. Hence, is the button 'make page fit the screen' necessary?
12. Another effect of maximising the size of the screen is that the operator will be flicking between pages, when they will really want them to be reviewed side by side.
13. There is an inconsistency with the video and pictures. While you cannot have both a text document and a photograph or a text document and video displayed at the same time, you can have a photograph and video displayed at the same time. This inconsistency may confuse the operator.

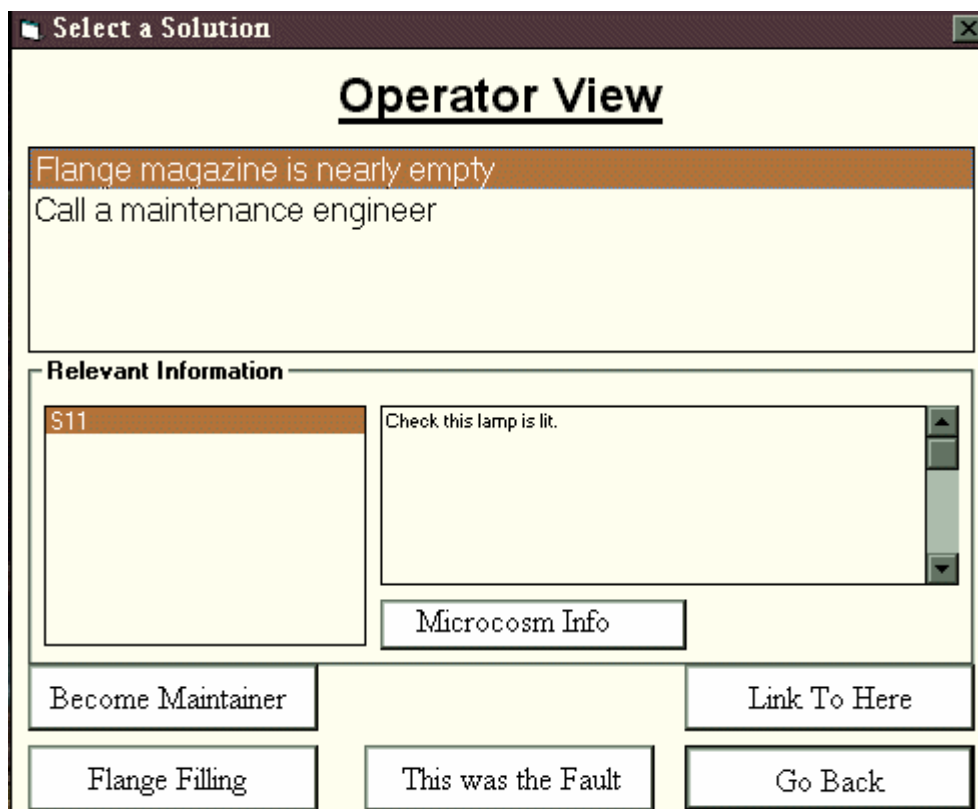
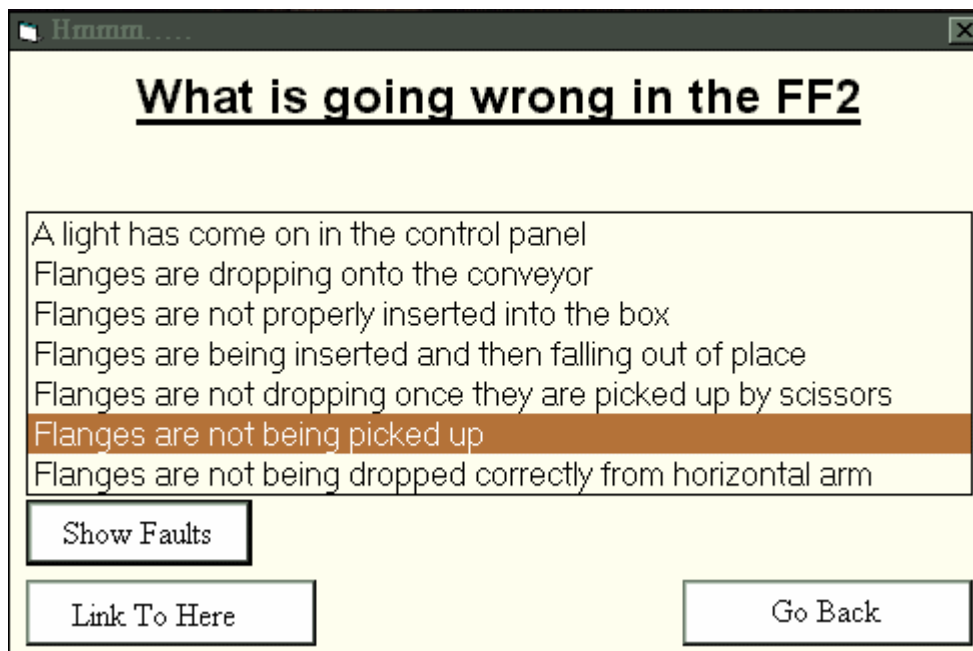
14. Using the graphical interface page R2 Set-up, it was unclear as to what the next selection should be and that selecting a button will lead to more information on setting-up.
15. In addition, due to the shading on the R2 page it was not clear where an item on the machine is actually located (Operators will generally know from experience of the precise location?)
16. Also on the R2 Set-up page if you select item 4 then 5, item 4 is closed down and removed from the toolbar. Hence, to go back to item 4 you have to re-select the R2 set-up page, then re-select item 4.
17. When you re-select the Set-up screen the machine button over the machine name R2 is highlighted. This may confuse the operator, i.e. what is the machine trying to tell me?

Scenario 2: Final Checks On Set-up

1. Killing the windows using the icon marked as a cross in the top right-hand corner of the window, may confuse non Windows 95 users. This could be solved by using a clearer icon or providing a facility to shut windows down using the tool bar.
2. One into the final checks document, vague instructions with no links out of the page where found. For example the first line said to check the materials, what materials and where? Also on the next line it was not clear as to whether the machine V4 is called the cardboard folder or the cardboard folder is in the machine V4.
3. The system has taken away control of the real estate from the operator, if they had some control over the display, it would give them enormous power over the information domain.
4. The fixed tool bar quickly become cluttered, obscuring the actual titles of the open documents. The toolbar truncated the title often (due to poor titles). There were the same titles on the toolbar for two different drawings. This could be overcome by using a selectable scrolling list of open documents using words or icons to represent the documents.
5. Since this project was designed, both the graphics and RTF viewer have been enhanced. Combined with the ability to use footnotes in Microsoft word 7, annotation can be added to links. This is especially useful where the text is very short.
6. A help facility is required, that is a 'find more' or 'selection' button, as no generic links were found on any key words or terms.
7. For operators the present toolbars with the standard Microcosm menus on, needs to be removed. As few, if any are used by an operator and may lead to confusion. The only ones that may be used, but were not displayed are from the toolbar in the RTF viewer (selectable under options) they are 'close window' and 'show links'. However on requesting 'show links' the Microcosm dial-up-box has a number of confusing descriptions.

Scenario 3: The flanges on the boxes are not being picked up, machine FF2.

The screens two main screens viewed in this section where:



The button style has changed on the 3D model of the packaging line, and is inconsistent with the style used in the rest of the application.

1. Completely different style of dialogue boxes used for the fault finding documents and hence may confuse the operator.
2. The operator is able to open and display more than one document at a time. This is inconsistent with the rest of the application.

3. When you have located the fault in the fault tree, you cannot go to the next document by double clicking, you need to select the 'Show Faults' button. This is inconsistent with the remainder of the application.
4. On selecting the 'Show Fault' for the fault 'Flanges are not being picked up', the next page confused the expert reviewers. The main reason being that titles were non-descriptive, also descriptions were mixed together with actions in the same dialogue box.
5. A suggested solution was to use the following headings.

<u>Fault Type</u> (copy of fault from 'Show Fault')
<u>Possible Causes.</u> Then list the possible cause, for example Flange magazine nearly empty.
<u>Identifiable Symptoms.</u> The list will change depending on which possible cause is highlighted.
<u>Action.</u> The list will change depending on which identifiable symptom is highlighted. If 'non of the above' is selected, then the action will be
Buttons along the bottom if necessary.

Feedback from expert review. Group 2. Dr Emilia Mendes, Mark Weal.

Scenario 1 : Setting up of the cable Laying on machine R2.

1. No text explaining <> buttons, if they are not available (disabled) they should be 'greyed-out' . At present they are coloured icons and appear as if they could be used for something, but the operator is unsure as to what.
2. On Start-up all buttons not available for selection should be 'greyed out'.
3. Also if you are an operator why do you need a maintenance button. Therefore after logging in buttons need to be greyed out.
4. In the case of a button being 'greyed out', the text description should still be displayed on the tool bar or as a pop-up menu.

5. The last message explaining the action of a button (displayed on the status bar of the Toolbar) remains, when the cursor is removed from the toolbar. There should be at least a default message. For example when you point to the Set-up point the message is still displayed from the last button looked at (as the Set-up, Maintenance, and Faults buttons have no message displayed).
6. Maximise window icon, does not symbolise the action it undertakes.
7. Similarly the 'select a document', 'find an electrical item', and 'find a terminal icon' does not symbolically represent the action it undertakes. Could use say an electrical component for the electrical icon etc.
8. The icon used to shrink the tool bar is commonly used for a 'play' command on most domestic equipment. This can be confusing to the operator.
9. On selecting the Set-up screen, no scroll bar is visible and the menu (a list of other screens) is obscured by the tool-bar.
10. The order of the menu in the bottom left-hand corner of the Set-up screen, should reflect the order of the most frequently used screens.
11. When placing the cursor over a button in 9 above, the pop-up help information is exactly the same as the information inside the button. Also at the same time it obscured the other button. Hence there is no need for the pop-up help.
12. When zooming in, on the set-up screen, the tool-bar obscures the scroll bar. You have to remember to remove the toolbar.
13. On the net screen, R2 Set-up, the image is slightly obscured by the toolbar.
14. Text is not readable as you zoom in. Here the pop-up help may be an advantage.
15. The pop-help is the same as the text box.
16. Are the Numbers important? If so there needs to be a Menu or Key, or as you step through the system the next one comes up.
17. Text screen has a number of typing errors.
18. Also some of the text is confusing, i.e. scale on dial in mm, is this obvious?
19. The help function on the RTF viewer are displayed on the status bar which are obscured by the toolbar.
20. Selecting the photograph brought you to a dead end (no clear exit).
21. The button colours are not of such a different colour (hue) to be distinguished from the text.
22. Also the button marked 'video', video of what, more information is required.
23. The video did not work the first time.
24. The history on the tool bar, is probably best replaced as a button, giving the complete history, perhaps with the last few opened documents on the toolbar.
25. Should the operator be able to edit links!? This command needs to be removed.
26. Should the operator require 'Open File'?

27. Need to look at the functions offered my Microcosm, and remove all those that are not relevant to the operator and any other non authors.
28. It was good that the Set-up button had a black edge during the set-up, reminding you that you were in the set-up mode.
29. The number of levels (of a hierarchical structure) were kept low. This was good too many levels will often confuse operators (they get lost too easily).

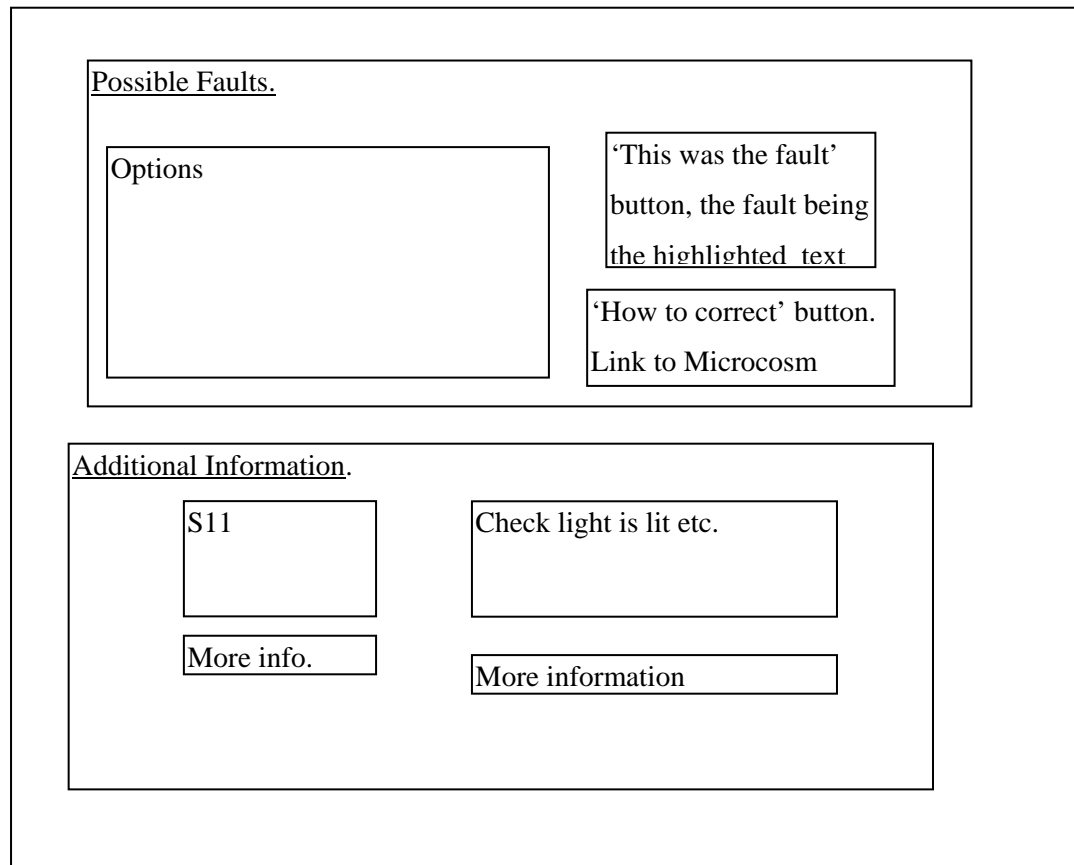
Scenario 2: Final Checks On Set-up

1. This is shown simply as a list. It would be good to have a method of showing that the tasks have been carried out. Perhaps, a dialogue box to be clicked when task is completed with a tick displayed on next to each completed instruction. Especially as several instruction involve navigating the resource base.
2. No links out of the page! Some are required.
3. The instruction 'check all materials' should have a link to a set of documents that the operator can step through (and tick off).
4. Have no hidden links. However if this was the case, the text could be a sea of buttons you may be able to make generic links selectable, that is display generic links. As too much time is wasted in selecting a piece of text and then selecting find/show links.
5. Once the operator has completed the tasks, they have to deselect all the windows. There should be a way of automatically closing all open windows once the task is complete. (also give the operator a sense of achievement.)
6. On most of the screens there are random numbers the right-hand side of the status bar! These are actually offsets, not need by the operator.
7. The background to the document should not be bright white, as this hurts the eyes after a while, use grey or off white. Notes could have a yellow background, similar to post-it notes.
8. Where only part of the system is in electronic format, a cross reference to the paper system needs to be visible (page chapter numbers etc.).
9. The system should give feedback that the task has been completed before closing down the documents.

Scenario 3: The flanges on the boxes are not being picked up, machine FF2.

1. Style of links not consist with the remainder of the application.
2. A dialogue box to type in the fault may be quicker than going down several levels of the model.
3. Two documents opened at he same time, this is an inconsistency.
4. One of the dialogue boxes was obscured by the toolbar.
5. Experts were confused as what to do!!
6. Unable to follow any links from S11, even though highlighted. Operator has to high light the text and the Microcosm infomation.

7. Why the term Microcosm, does the operator need to know that they are not using Microcosm.
8. No clear exit.
9. Should be operator or maintainer not both on the same screen.
- 10.Boxes, fonts, colours not consistent with the rest of the application.
- 11.On hitting 'this is the fault' the system should shut down and go back to the start.
- 12.A suggest layout of the screen is as such.



Scenario 4. Find out about electrical Part Y145 on machine FF2.

1. The screen naturally leads to the find button, which is active. If this button is selected before a machine area is selected, a spurious list of links is produced. Hence the button needs to be 'greyed out'.
2. On the pictorial representation of the manufacturing line use bright green for the main machine and dark grey for the other machines. This will let the machine stand out more, also a title for each box is required.
3. The resulting dialogue box is title 'session 18' what does this mean.
4. The resulting list of links, should this be in any particular order?
5. If you close the dialogue box with the result of the search, you have to start all over again, remembering how you got there.

6. Once the list has been created, it would be good to be able to step through the list. Using the arrows on the toolbar, perhaps?
7. Could the search be made into a small guided tour?
8. The search could remain until the end of the session. Perhaps saved as a search, with a button for quick access.
9. On selecting the flange feeder diagram, the destination link is highlighted with a red box. However as this is a bitmap and all links are red boxes it is not very clear as to which are the destination links. Some text labelling would help

Scenario 5. The flanges on the boxes are not being picked up, machine FF2.

Similar problems encountered to operator in scenario 3 above, plus;

1. As a maintainer 3 possible faults are shown. On the third fault two options are open to the maintainer. It is difficult to select text that has a link in it.
2. One of the resulting screens brings up a diagram. Yet is titled 'bitmap'. Do the users need to know that it is a bitmap?
3. One of the links was from the text to check the status of Y131. Yet you were unable to link from Y131, to find out what it was. This would reduce memory load.
4. The error message 'no link found', does not help the user. More information is required.
5. A notepad would be useful, as you can forget what the aim of all the searching is for.
6. A note pad would also enable a maintainer to make notes as they go along, for example write down the settings of a control panel.
7. Also you could show the control panel as a screen, with either the current settings, or allow the maintainer to enter the settings they see.

31-34, and 36.

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Appendix F. Comments by expert reviewers for Case Study Review.

F1.1 First Review Expert Reviewer ER4

F1.2 Expert Task 1 (ET 1)

- There are two similar looking buttons on the front of the computer. It is not clear which one is the power button.
- The system displays the choice of operating system for a count of 30 seconds. Could this be changed to just a few seconds as the operators will never require to change the default setting.
- The blue screen that appears as the system is booting into Windows NT does not display any useful messages to the users. Could a message be displayed to tell the user it is booting up and to wait?
- Could the welcome screen become full size on switch on as half the options could not be seen without scrolling down the page?
- Additional comment by David Humphreys can we stop shop floor operators loading games etc onto the machine at night by password protecting the floppy and CD drives.

F1.3 Expert Task 2 (ET 2).

- The toolbar blocked the bottom of the RTF viewer. Hence, it was not possible to scroll down to see all the information. As the windows were SHEP controlled it was not possible to resize them as a user, this was a major problem.
- When using the Eurotherm manual if the right hand window was closed, the display did not revert to the main contents on left pane and chapter contents on the right pane.
- Next page button only displayed the chapter contents in sequence and not the individual pages. However the expert review could see what was trying to be done and thought it would be a useful tool when it was working.
- The links to the bitmaps and DXF drawings were missing and hence the reviewer could not evaluate their effect at this stage of the evaluation.
- The table in chapter 4 could not be read, as only part of the table could be seen and no scroll bars were available at the bottom of the window.
- The close button on the toolbar was useful in clearing the manual pages. The expert review was not sure what it was intended to do but intuitively released the button was to close the manual.

- The follow single link was turned back on, as the reviewer realised that a result box to follow single links was a waste of time and made navigating between nodes difficult.

F1.4 Expert Task 3 (ET 3)

- The header of the contents page is too long hence to see the contents list the user needs to scroll down the node. Therefore, this node needs to be split into two separate ones.
- The displaying of a bitmap from the thumb nail sketch was cumbersome. In that the size of the viewer was so large that, it would not fit on the screen. Some form of size control is needed, either by the author or by SHEP (which the author sets). However the expert review liked the thumb nail approach as it did not interfere with the reading the text, yet the user can see the diagram in more detail if required.
- Again tables were hard to read.
- Although the system showed links to the Siemens motor and the Gearbox, the reviewer was unable to follow them. The error message was no document found. However the system still opens a blank viewer, which could not be closed until the user exited the FIRM system.
- The only way to access the history filter is through the filter manager. Could a button be added to the tool bar.
- The history filter gives a list of all documents visited. Is it possible while navigating to mark a document as of interest and display a symbol to that effect in the history list?
- The control of bitmaps was outside SHEP although they form part of the document set. Hence, these appear in the middle of the screen and obscure the text. In addition, when you close the manual these still remain displayed.
- A general comment is that it would be very useful, especially for the novice users to have one button that will clear all viewers and display a default menu.

F1.4.1 Expert Task 4 (ET 4)

- The line diagram was not included, however the main menu did distinguish between the two machines.
- A designation between clusters and actual documents. Could we prioritise them so that the documents are on top of the clusters, or give an option?
- The DXF drawing came to the front then disappeared, this happened a couple of times.. This could have been due to the sensitivity of the touch pad mouse.
- When navigating documents that are not contained within a manual, it does not take long before the screen gets confusing, as previous windows are left open and remain displayed, when a document is selected. Therefore, could the factory floor operator only see one document at a time?

The observation made by the reviewer fall into 3 categories, those referring to:-

- Content (9, 13, 21)
- Presentation (4, 7, 8, 10, 14, 15, 22)
- System (1, 2, 3, 5, 6, 11, 12, 16, 17, 19, 20, 23, 24)

In the categorisation of the observation, some of the observation can clearly be place in a number of categories. Hence, the observations are place in the category that best represents the main concern of the observation. There were some positive comments as well as the criticism (11 and 14).

The observations that most concerned the expert review were (6, 7, 10, 20, 24).

F1.5 First Review Expert Reviewer ER 1 and ER 2

F1.5.1 Expert Task 1 (ET 1)

- The reviewer is presented with a choice of operating systems, which version do they choose? If there is only one option can the PC just boot straight into the appropriate operating system.
- The reviewer is required to log on twice. Once for the operating system and again for the FIRM system. Hence, could we set the system so that the reviewer logs in once and the system logs the reviewer into FIRM?
- At the FIRM log in, the reviewer name is highlighted and not the password box. The danger is that the reviewer starts to type the password and in doing so deletes the reviewer name.
- Once logged on the reviewer is presented with only the one option of Supertension Sheathing Line. It is not obvious that they are required to press return could the application autostart?

F1.6 Expert Task 2 (ET 2).

- The header of the contents page is too long hence to see the contents list the reviewer needs to scroll down the page.
- The reviewer naturally went to a subject heading (heading level 1) and tried to follow links. The only links were on the sub-headings. Hence, it may be worth linking the subject heading to the first of the sub-headings.
- The displaying of a bitmap from the thumb nail sketch was cumbersome, that is, the bitmap was wider and deeper than the screen. The figure needs to be about a third of its present size, otherwise, this will confuse the operator as it is difficult to resize the window, due to it being so large.
- The system showed links to a number of bitmaps and documents for example the Siemen's motor, yet the reviewer was unable to follow them. The error message was no document found. However, the system still opens a blank viewer, which could not be closed until the reviewer exited the FIRM system and the toolbar went behind the taskbar.
- When bitmaps were displayed, the initial position was such that the top border was off the screen. Hence, it became difficult to move the windows.
- When the reviewer zoomed into a diagram using the bitmap viewer, the window would resize itself. In doing so, the task bar was not fully displayed. Only the first few icons could be seen and used, i.e. tool bar does not wrap.

F1.7 Expert Task 3 (ET 3)

- Selecting Eurotherm manual from the menu did not take the reviewer to the main contents page of the Eurotherm Manual.

- The table and figures that are imbedded into the document could not be read, as only part of the table or figure could be seen as no horizontal scroll bars were available and the SHEP system would not allow the reviewer to adjust the size of the two panels
- No guide tour available.
- The information is actually required at the point of use, away from the proposed PC. Is it possible to have a print command or some other method of providing the shop-floor reviewer with the information? This is especially important if the system is to replace the paper copies.

F1.8 Expert Task 4 (ET 4)

- The DXF drawings come to the front then disappear, this happened the first time that the reviewer opened a drawing. However on the second occasion it remained open.
- When the expert reviewer zooms into a DXF drawing they can zoom-in by stages. However they can only zoom out by using the centre drawing and fit to window button.
- The touch sensitive pad was awkward to use. The reviewers found it difficult to select the text that they required. The system would often highlight several lines of text. It appeared as if the first touch was interrupted as a tap and subsequent movement as a command to highlight the lines of text. While in reality the reviewer was simply trying to move the cursor.
- The use of the DXF viewer raised a number of issues.
- How will a set of drawings be viewed by the user? Many larger A0 drawings are dissected in smaller drawings often containing a lot of detail.
- Drawings are often used in conjunction with manuals. How will we display both?
- Drawings often flow from one to another. How will we facilitate that?
- If we use a large electronic drawing rather than dissect the drawing, will the birds eye view be legible.
- The user will often put diagrams side by side to see the complete system, can this be achieved with the real-estate of a 17 inch monitor.

The observation made by the reviewer fall into three categories, those referring to: -

- Content (39, 30, 32, 35)
- Presentation (31, 33, 34, 39, 40, 42)
- System (25, 26, 27, 28, 36, 37, 38, 41)

In addition to the wider issues of the cursor control and viewing technical drawings the observations that most concerned the expert review were those numbered 25-28.

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Appendix G. Data from user trials.

Impression- the users feelings or emotions when using the software.	Agreed	Disagreed
1. The system is one that I would want to use on a regular basis.	83	
2. The system was very demanding and not enjoyable to use.		100
3. This high-tech route to information is intimidating		91
4. The system was frustrating to use.		100
5. I would recommend this system to my colleagues.	83	
6. I enjoyed working with this system.	70	
7. This system was really very awkward to use.		100
Command - the measure to which the user feels that they are in control.		
8. The system was responsive to my inputs	91	
9. I did not find it easy to start the application		87
10. I felt I had no control over the system		100
11. The system did not respond quick enough to my selections		91
12. If the system stopped working it was not easy to restart it.		100
13. It was easy to make the system do exactly as I wanted.	78	
Effectiveness - the degree to which users feel that they can complete the task while using the system.		
14. To get to the information I needed was straight forward.	91	
15. Using the system hindered the task I was undertaking		83
16. I was not able to find the information I required		100
17. There are too many steps required to get to the information.		74
Navigability - The degree to which the user can move around the application.		
18. It was easy to move around the information.	78	
19. There were plenty of ways to find the information I needed.	87	
20. The toolbar provided useful short cuts.	83	
21. I could find my around the information using the menus and content pages.	65	
22. It is easy to become disoriented when using the system		57
23. I Knew where to go next with the system.	57	
Learnability - the degree to which the user feels that the application is easy to become familiar with.		
24. I felt safer when using only the method I was familiar with to find the information.		57
25. The guidance given before using the system, was enough to use the system	91	
26. I felt safe trying different ways to get to the information.	74	
27. Learning to use the system was easy.	78	
Aidability - the degree to which the application assists the user to resolve a situation.		
28. The system was helpful in coping with the error	78	
29. The system help files provide enough information	83	
30. I was unsure if I was using the right command.		96
31. There was not enough information displayed on how to respond/proceed.		87
32. I found the system awkward to use if I wanted to do something out of the ordinary		74
33. I could not understand or act on the information provided by this system.		96
Comprehension: - The degree to which the user understood the interaction with the application.		
34. The information was clearly presented and understandable.	96	
35. The information displayed was inconsistent.		96
36. The actions associated with the buttons on the main toolbar were easily understood.	87	
37. The screens became cluttered and confusing		83
38. I understood the action of the window's tools bars.	78	
39. I understood how to operate the system.	78	
40. To get to the relevant information I had to scroll down the page		78
41. The layout of the manuals was satisfactory	78	
42. The buttons were clearly visible in drawings.	83	
43. Too much text was displayed at any one time		74

Table G -1 Percentage of Personnel who answered with a positive response.

G1.1 Data from Timed Trial

	Staff	Operators	Maintainers	all Pirelli	Ford	ALL
Impression	0.904	0.429	0.685	0.695	1.267	0.894
Command	1.000	0.417	0.733	0.744	1.020	0.840
Effectiveness	1.250	0.750	0.625	0.766	1.125	0.891
Comprehension	1.100	0.400	0.430	0.560	1.000	0.713
Navigability	0.555	-0.167	0.300	0.288	0.666	0.420
Learnability	0.166	-0.500	0.500	0.300	0.906	0.510
Aidability	0.571	0.000	0.416	0.411	0.979	0.173
Overall	0.844	0.220	0.518	0.544	1.000	0.702

Table G- -2. Table of normalised scores from questionnaire after training.

User (actual order) Electrical	Task1 P	Task1 H	Task1 Diff	Task2 P	Task2 H	Task2 Diff	Task3 P	Task3 H	Task3 Diff
1	64	82	-18	230	106	124	217	89	128
2(3)	180	59	121	150	54	96	94	27	67
3(4)	48	32	16	249	65	184	110	47	63
4(7)	92	88	4	310	79	231	377	54	323
Mechanical	Task1 P	Task1 H	Task1 Diff	Task2 P	Task2 H	Task2 Diff	Task3 P	Task3 H	Task3 Diff
1(2)	74	86	63	136	11	42	44	33	103
2(5)	87	93	57	120	30	44	49	57	63
3(6)	108	190	46	187	62	150	40	40	147
4(8)	153	86	119	56	34	39	47	56	0
5(9)	265	88	245	120	20	50	38	35	85

Table G- 3 Table of data from time trials:- the time taken to complete the tasks.

User (actual order)	Task Paper	documents visited	short cuts	Time to Complete	lost	Task Hyper- Media	nodes visited	short cuts	Links used.	hot keys	Time to Complete	Lost
1 (1) Elect	1	11	0	64	0	1	7	3	5	0	82	0
	2	21	3	230	2	2	6	2	4	0	106	0
	3	12	3	217	1	3	6	3	4	0	89	0
2 (3) Elect	1	6	0	180	0	1	6	4	4	0	59	0
	2	11	0	150	0	2	7	6	5	0	54	0
	3	10	1	94	0	3	4	2	2	0	27	0
3 (4) Elect	1	6	0	48	0	1	6	4	4	0	32	0
	2	13	2	249	2	2	6	3	4	0	65	0
	3	5	1	110	0	3	3	1	1	0	47	0
4 (7) Elect	1	8	0	92	0	1	7	4	5	0	88	0
	2	15	1	310	1	2	6	3	4	0	79	0
	3	26	1	377	1	3	5	2	3	0	54	0
5 (2) Mech	1	8	2	74	0	1	3	2	1	0	11	0
	2	7	0	86	0	2	4	2	2	0	44	0
	3	8	1	136	1	3	5	1	3	1	33	0
6 (5) Mech	1	14	3	87	1	1	3	2	1	0	30	0
	2	14	1	93	0	2	5	2	3	0	49	0
	3	5	2	120	0	3	5	1	3	1	57	0
7 (6) Mech	1	11	4	108	0	1	7	4	5	0	62	1
	2	16	1	190	0	2	5	2	3	0	40	0
	3	16	2	187	0	3	5	1	3	1	40	0
8 (8) Mech	1	18	2	153	1	1	4	2	2	0	34	0
	2	11	2	86	0	2	5	2	3	0	47	0
	3	12	1	56	0	3	5	1	3	1	56	0
9 (9) Mech	1	29	1	187	1	1	4	2	2	0	40	0
	2	13	1	56	0	2	5	2	3	0	56	0
	3	10	1	120	1	3	5	1	3	1	35	0

Table G-4. Usability data from timed trial, using maintainers from Pirelli shop-floor.

G1.2 Data from Repeated Timed Trial

	After Training	Timed Trials	Repeated Timed
Impression	0.69	0.98	0.97
Command	0.73	0.86	1.04
Effectiveness	0.63	0.94	1.00
Comprehension	0.43	0.81	0.85
Navigability	0.30	0.93	0.93
Learnability	0.50	0.89	0.71
Aidability	0.42	0.69	0.67
Overall	0.52	0.68	1.03

Table G- -5. Table of normalised scores from repeated timed trials.

User (actual order) Electrical	Task1 P	Task1 H	Task1 Diff	Task2 P	Task2 H	Task2 Diff	Task3 P	Task3 H	Task3 Diff
1 (2)	95	120	36	265	59	36	84	32	233
2 (4)	203	199	148	178	55	112	87	22	156
3 (5)	55	44	11	277	43	234	63	21	42
Mechanical	Task1 P	Task1 H	Task1 Diff	Task2 P	Task2 H	Task2 Diff	Task3 P	Task3 H	Task3 Diff
4 (1)	162	135	134	106	28	20	115	39	67
5 (3)	138	70	117	95	21	34	36	33	62
6 (6)	112	71	92	131	20	31	40	37	94

Table G- 6 Table of data from repeated time trials:- the time taken to complete the tasks.

User (actual order)	Task Paper	documents visited	short cuts	Time to Complete	lost	Task Hyper- Media	nodes visited	short cuts	Links used.	hot keys	Time to Complete	Lost
1 (2) Elect	1	6	0	95	1	1	6	4	5	4	59	0
	2	14	5	120	1	2	10	2	4	0	84	0
	3	11	3	265	1	3	3	2	1	0	32	0
2 (4) Elect	1	18	3	203	0	1	6	4	4	1	55	0
	2	23	5	199	0	2	8	5	6	0	87	0
	3	16	3	178	1	3	3	2	1	0	22	0
3 (5) Elect	1	7	0	95	0	1	6	4	5	4	44	0
	2	15	9	277	0	2	5	4	5	0	43	0
	3	6	3	63	0	3	3	2	1	0	21	0
4 (1) Mech	1	9	0	162	1	1	4	2	2	0	28	0
	2	15	2	135	1	2	5	2	3	0	105	0
	3	10	1	106	0	3	5	2	3	0	39	0
5 (3) Mech	1	16	3	138	0	1	3	2	4	0	21	0
	2	9	2	70	0	2	5	2	3	0	36	0
	3	7	1	95	0	3	5	2	3	0	33	0
6 (6) Mech	1	18	2	112	0	1	3	2	1	0	37	0
	2	5	1	71	0	2	5	2	3	0	40	0
	3	11	2	131	0	3	5	2	2	0	20	0

Table G-7. Usability data from repeated timed trial, using maintainers from Pirelli shop-floor.

G1.3 Statistical Techniques

A single factor repeated measure experiment undertakes the analysis of variance to determine whether the means of two or more related samples differ. Since measures from the same or similar cases are taken more than once, the analysis is often known as a repeated measure analysis [Cramer 1998].

Ordinal (rank) scales have some correspondence between the size of the number and magnitude of the quality represented by the number. These numbers do not indicate anything about the size of the difference. For example, these are used in questionnaires where user gives an answer on a Likert scale.

Ratio Scales are those that have a true zero point and the ratio of the numbers reflects the attribute measures. For example, 30 cm is twice as long as 15 cm. [Foster 98]

The tests for difference for ordinal data determines whether the distribution of cases differs significantly from chance across the groups or from some theoretical distribution.

Wilcoxon matched-pairs signed rank tests for two related samples. It not only takes the sign of the difference between the two samples but also takes account of the difference by ranking the size of the same sign. The test was used to determine whether there was a statistical difference between the responses given to the paper system and those given to the hypermedia system. By hand, the steps are:

1. Calculate the difference between scores and rank them by size ignoring the sign.
2. Give a rank of 1 to the smallest, regardless of sign and any omitted pairs where there is no difference. Where two or more differences are the same size, they are given the average of the ranks they would have received if they differed.
3. Sum the ranks of the difference in sign with less frequent sign.
4. For less than 26 differences, special tables are used. The value of the smaller sum needs to be less than, or the same as, the value in the table for that number of differences for a statistical significance.

The asymptotic method assumes that the data set is reasonably large, and that tables are densely populated and well balanced. If the data set is small, or tables are sparse or unbalanced, the assumptions necessary for the asymptotic method have not been met, and either the exact or the Monte Carlo method should be applied [SPSS 98].

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Appendix H Sample Times for Heuristic Effort Estimation.

	Scanned drawings	new Video	Converted		linkbase	MHAs	Size MB	links	time/ size	ratio links/doc	Time Estimated Hrs	Weight	Estimated Total hrs	Actual/Accurate Time. Hrs
			text	DXF										
LCU	19	0	11	103	3	1	46.4	478	1.2	4.2	18.25	3	54.75	57.13
Training	15	4	67	0	3	1	59.9	315	0.9	4.7	14.57	3	43.71	44
Caterpullar	0	0	16	43	4	1	19.3	190	1.2	3.2	7.28	3	21.84	23.21
Stripping	0	0	1	16	1	1	7.9	320	2.2	18.8	2.24	9	20.16	17.6
Installation	0	0	2	21	2	1	7.1	47	1.4	2.0	3.04	2	6.08	10.1
LCU Extension	0	0	7	30	2	1	14.3	46	0.7	1.2	4.62	2	9.24	10.1
Technical Instruction	0	0	2	23	3	1	7.94	39	1.2	1.6	3.38	3	10.14	9.17
Clean	0	0	11	0	2	1	1	52	5.9	4.7	1.42	1	1.42	5.4
GE Head	0	0	4	4	2	1	1.19	14	2.8	1.8	1.2	1	1.2	3.37
DC Cab	0	0	1	4	2	1	1.12	8	2.2	1.6	0.9	1	0.9	2.48

	Scanned text	drawings	thumbnail	linkbase	mha	Size MB	links	ratio links/doc	time estimate	Weight	Estimated Total hrs	Actual/Accurate Time. Hrs
Extruder	35	18	0	4	1	10.4	244	5	13.41	4	53.64	57
Crosshead	25	8	16	2	1	1.92	233	7	8.57	4	34.28	43.11
Autoflanged	18	5	5	2	1	2.52	137	6	6.02	4	24.08	32.91
DC Cabinet Eurotherm	1	5	0	1	1	0.8	142	24	1.62	5	8.1	12.04
Siemens Motor	26	15	11	3	1	3.66	71	2	10.48	2	20.96	28.75
Gear Box	6	3	0	2	1	7.68	187	21	2.51	5	12.55	17.01

Table H- 1 The data used to estimate the time to complete a similar MHA

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Table H- 1 The data used to estimate the time to complete a similar MHA..... 217

Appendix I.

A typical User Scenario.

The object of this appendix is to present the reader of this thesis with a typical scenario for the application presented in chapter 5. The user in the scenario is from the maintenance department. The user is informed that they are to undertake the maintenance program of the extruder, that is the replacement of the filter. As the hypermedia system runs on a general purpose PC on the factory floor, see Figure I-1, informing the maintainer of work to be undertaken or changes to schedules, can be achieved in a number of ways. One way is for the Senior Maintenance Engineer to place a revised work schedule in the virtual F drive of the appropriate department (more details of virtual drives in Appendix A), and if necessary e-mail the maintainer to inform them that a new schedule is available.

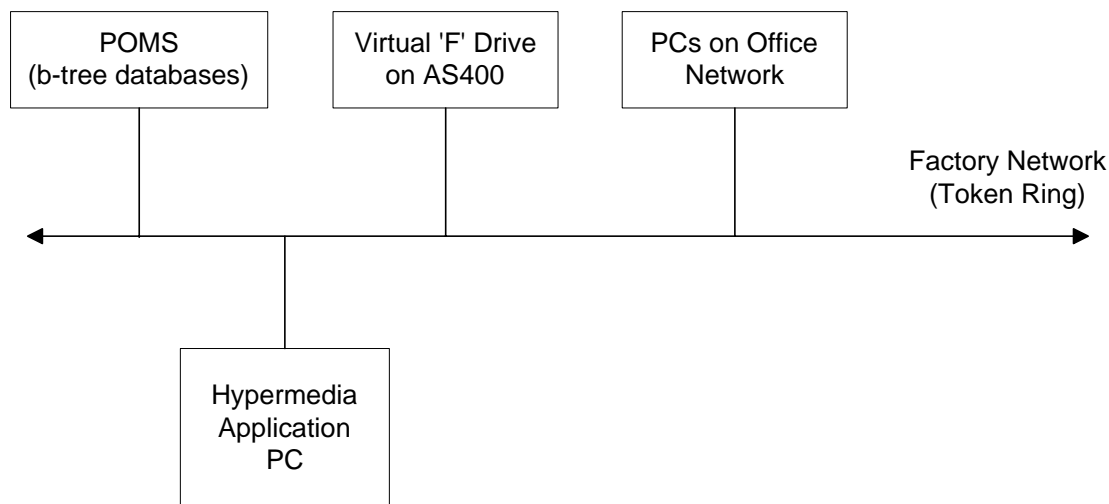


Figure I-1 The interface to the factory network.

To find the information the maintainer requires, they can start at the main menu, see Figure I-2. From here they have two options:

1. If they know the manual required the information they require is they can go straight to it from the main page.
2. They can search for the information, by using the text search, accessed through the search button D on the toolbar, see Figure I-3.

In this scenario the maintainer has chosen to search using the term extruder.

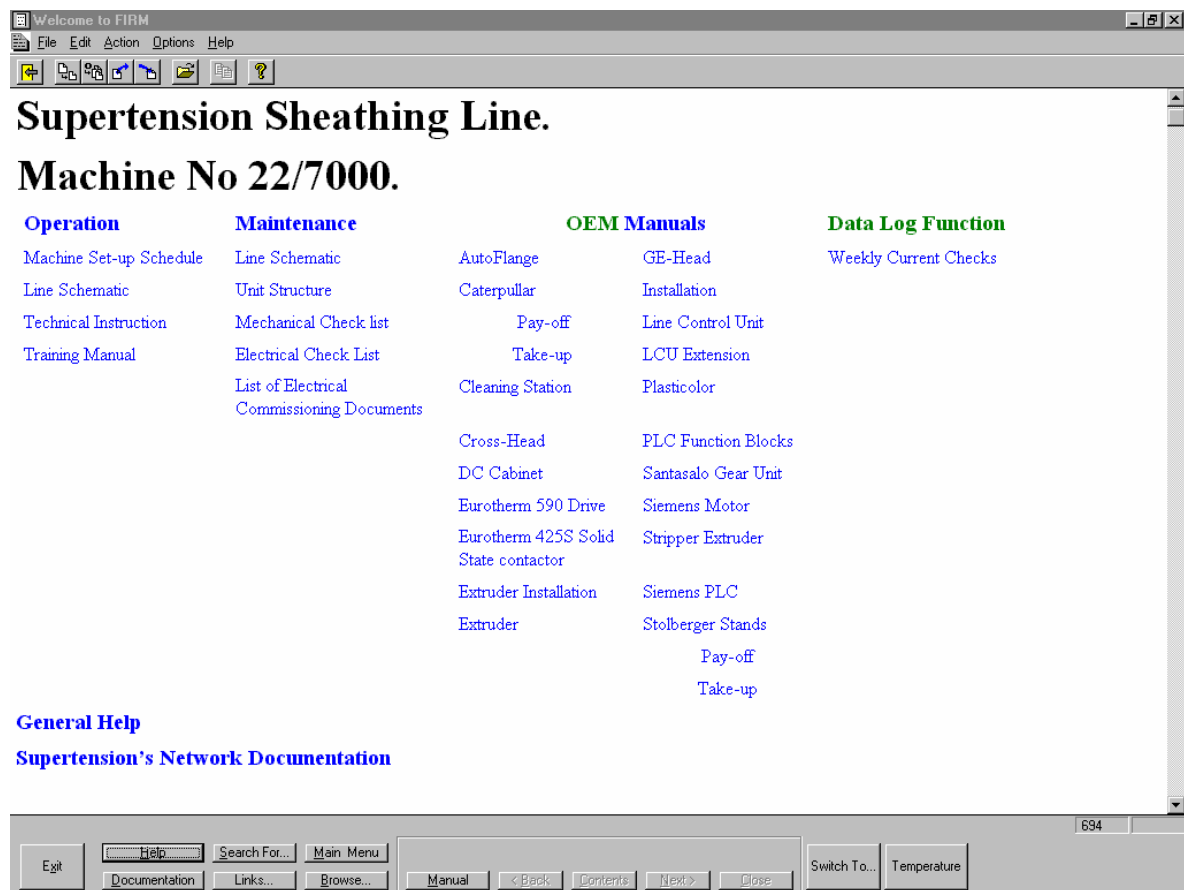


Figure I- 2 The main index page.

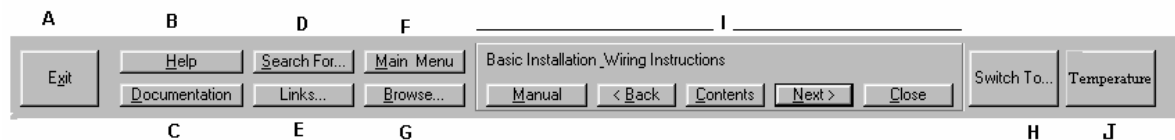


Figure I-3 The Toolbar showing.

The system will return a result box, similar to that in Figure I-4. The result box will allow the user to view the extruder manual, search all documents for the term extruder, view further cluster on extruder setting and extruder materials.

In this scenario the maintainer has chosen the extruder manual, and by selection of the appropriate section from the index has arrived at the manual, dealing with extruder on the Supertension Sheathing Line, see Figure I-5.

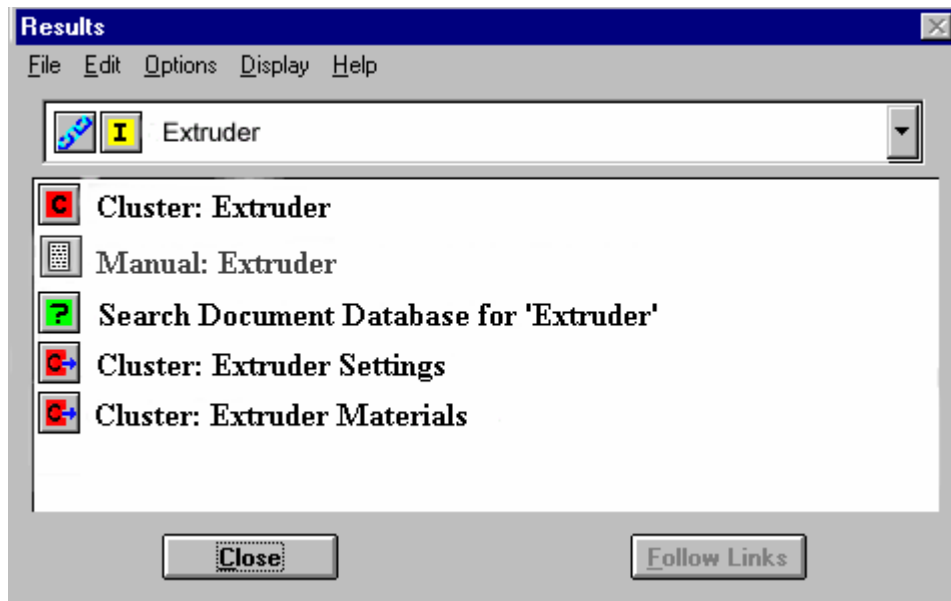


Figure I-4 The Extruder Cluster Interface.

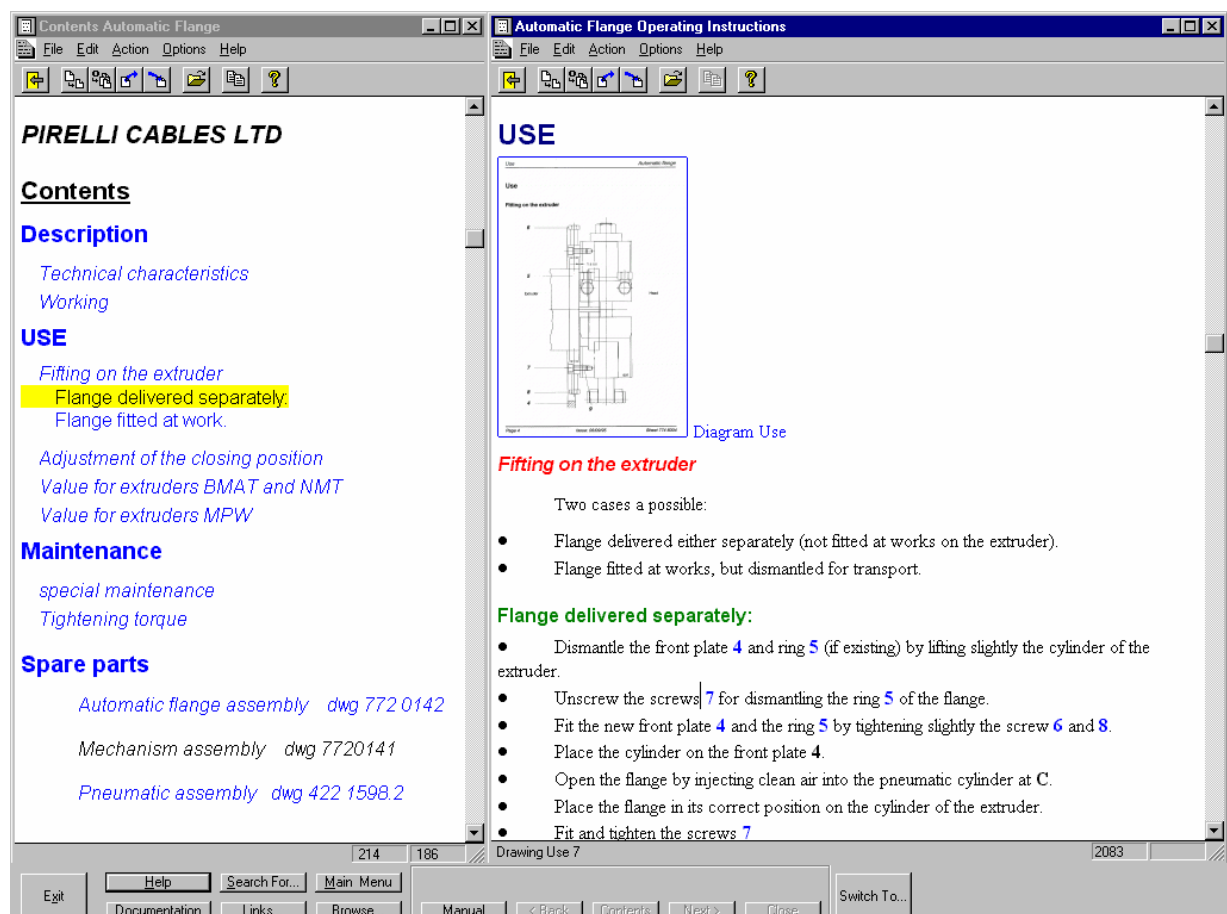


Figure I-5 The layout of a SHEP controlled Extruder manual.

The user selected the section labelled spares, selected the thumbnail of the filter. The SHEP system places the diagram on the left and a list of spare parts on the right, see Figure I-6.

Parts List

Part Number	Part Description	SC	Unit	Quantity	Drawing
047466	CROSSBAR L=52 NMT120 POS.3	P	UN	1	7641642 See page 2
397586	ADJUSTABLE ELBOW 10-1/4" POS.4	P	UN	2	
200909	TUBE D=10/8 POS.5	R	MT	0.300	
394050	FLOW INDICATOR DN15 NB 23-1204 POS.12	P	UN	1	
404007	COCK NB 2700-1/2" POS.13	P	UN	1	
689026	ELECTRO-VALVE TYPE 121KO1 POS.14	P	UN	1	
553011	DOUBLE NIPPEL GF530 → 1/4"-1.50" POS.20	X	UN	2	
500102	MIXED ELBOW 1/4" GF POS.21	X	UN	2	
524105	MIXED REDUCER 1/2"-1/4" GF241 POS.22	X	UN	1	
394051	MIXED CONNECTION UNION 3/4"-1/2" POS.23	P	UN	1	
524115	MIXED REDUCER 3/4"-1/2" GF241 POS.24	P	UN	1	
403030	MALE REDUCER 3/4"-1/2"-R-209 POS.25	P	UN	1	
524505	MALE REDUCER 1/2"-1/4" GF245 POS.26	X	UN	1	
393030	FILTER FN16 NB 1715-3/4" POS.27	X	UN	1	

Figure I-6 Drawing and Parts List of Filter.

From the drawing the maintainer can select an item number, the description and part number are then highlighted on the parts lists (i.e. POS.27 for the filter.)

In the column next to the description is that of Nokia's part number. By selecting the part number (the maintainer double clicks the link) a search is made of the Pirelli spares database (see Figure I-7) held on the AS400 is made, see Figure I-1.

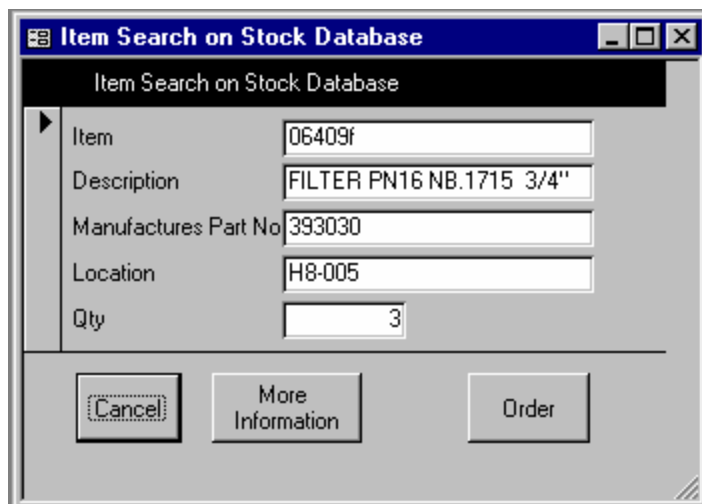


Figure I-7 Result Box for search of part number in the Pirelli's spare database.

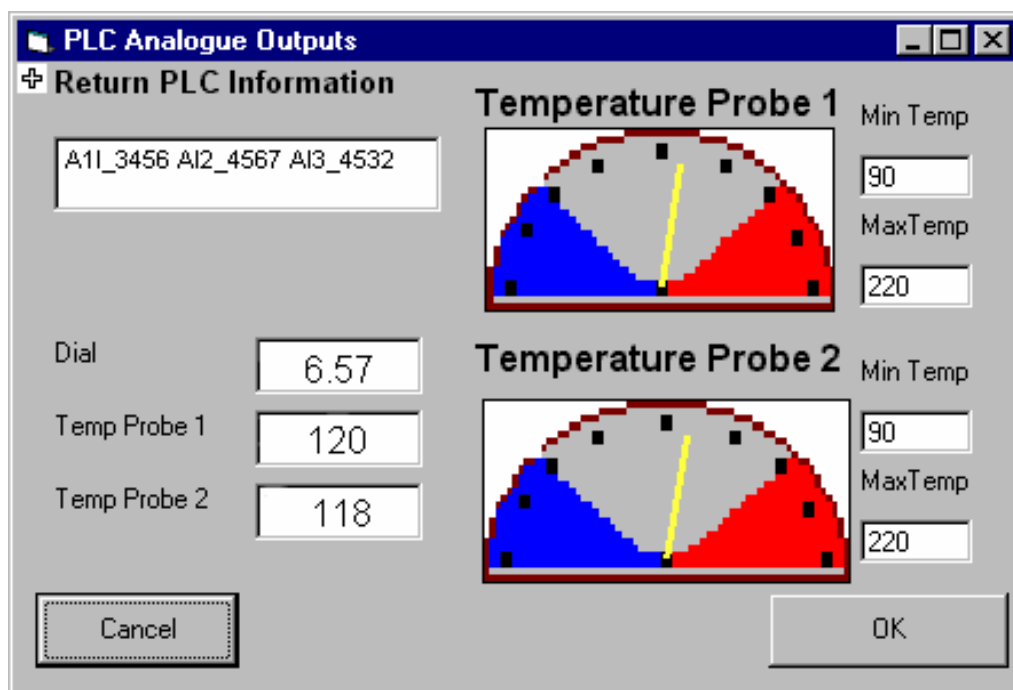


Figure I-8 The PLC interface

Once the filter change has been completed the maintainer can monitor the operation of the extruder via the connection between the hypermedia system and the PLC for the line, an example interface is shown in Figure 1-8.

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