Continuous improvement through innovative information management

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Benny Tjahjono & Richard Greenough

<b.tjahjono@cranfield.ac.uk> & <r.m.greenough@cranfield.ac.uk>

School of Industrial and Manufacturing Science

Cranfield University

Cranfield, Bedford MK43 0AL

United Kingdom

Abstract

Innovation remains central to competitiveness. Most manufacturers, regardless the products, share a common set of challenges: improving quality, reducing wastes and optimising productivity; and at the same time striving to be more responsive to the customers' demand. For those reasons, manufacturers tend to rely upon accurate, timely provision and management of information to support particularly manual, operative tasks. The paper describes some insights from a study of the development and implementation of information systems to support continuous improvement initiatives at two global manufacturers in the UK. The study has revealed typical problems associated with managing abundant information and suggests an innovative method of addressing the problems. The method ensures the provision of task-related information that is accurate and concise, delivered only when and wherever needed, and is adapted to the users' levels of skill. The benefits of the proposed method include improved accuracy of information, time/cost reduction and increased efficiency.

1. Background

Global competition has imposed on manufacturers the requirements to improve quality and at the same time to reduce cost. These requirements have had a dramatic impact on manufacturers who must increase flexibility and productivity while minimising wastes as much as possible. In addition, they must be able to rapidly react to today's dynamic, customer-driven market. For those reasons, manufacturers tend to rely upon information systems. However, in spite of the advances in computer and Internet technologies, so far, the way the information is presented to the shop floor personnel has not directly supported the task at hand.

In some cases, although the information may have been made available, it needs to be accessed as required. In many cases, the information is held by manufacturing engineers or managers, making it difficult for shop floor operators to obtain the required information related to the task in a timely manner. Additionally, technical information about manufacturing processes is available only during the training programme after which the shop floor operators will have limited access to further information.

Shop floor workers are required to perform a wide-range of tasks and hence to familiarise themselves with a wide-variety of task procedures. They may be rotated through different jobs with similar levels of skill and their jobs may be enriched with more responsibilities. For these reasons, information support should be available on-demand, whenever needed to ensure job performance.

The complexity of many products and processes, together with today's advanced technology, generates abundant information that is generally less structured and unsuitable for all levels of expertise. This may consequently cause information overload, where shop floor operators are presented with too much information that they may not need at one point in time.

Despite the widespread use of computers in industry, 80% of today's technical documents, for example manufacturing procedures for assembly and maintenance, still exist in paper-based format [Lundeen, 2000]. These documents are written mostly using text that provide only limited 'know-how' on manufacturing processes. In order to explain a long procedural task fully, a large amount of text would be required which otherwise may lead to ambiguity and comprehension problems. Paper-based technical documents also cause difficulties in accessing the information due to the presence of cross-references. Reading the documents with persistent cross-references, for instance between text, engineering drawings, circuit diagrams and component specifications, can be time-consuming and prone to error.

The above issues suggest that if manufacturers rely upon information to improve productivity and performance, then they need to manage information better. In other word, the system to manage the information should be able to provide:

- Accurate, up to date information to ensure the correct operations (***what information is provided***)
- Accessibility to the relevant information directly from the point where the task is carried out (***where information is provided***)
- Timely, on-demand information delivery (***when information is provided***)
- Consistent transfer of knowledge and process know-how to shop floor personnel (***how information is provided***)
- Right amount of information delivered at any one time (***how much information is provided***), and
- Presentation of information that can be customised dependent upon users' preferences and level of expertise (***for whom information is provided***)

2. Information management using hypermedia technology

The means of providing and managing information in today's complex and dynamic manufacturing environment needs to be task-related. The information itself may include textual instructions, pictures, or schematic diagrams that must be presented simultaneously. Hypermedia technology is suitable for this purpose, because it is capable of linking various media and presenting support information according to the task in hand. It enables various types of information to be connected to each other and allows the user to navigate through the information base in a non-sequential way.

The term hypermedia was originated from hypertext, invented by Ted Nelson in 1965. Hypermedia differs from hypertext in the way in which a user can navigate in a non sequential fashion between pictures, sounds and videos, in addition to navigation between texts. Typical examples of hypermedia systems include the web, Windows Help system and Microsoft Encyclopaedia.

In addition, literature has pointed out the following reasons to use hypermedia as an information management tool.

1. The hyperlinks in a hypermedia system mimic how a human brain associates pieces of information through non-sequential access and uses this relationship to construct understanding of the information [Marchionini and Schneiderman, 1988]. Browsing the information from a textbook would be an example of this. Instead of reading from the beginning to the end, very often a reader would start from the table of contents, identify the topic of interest, and go to the topic, skipping the other chapters.

2. The use of multimedia objects can help people build understanding, particularly in the procedural task of operating a system [Najjar, 1995]. Mayer and Anderson [1991] found that the use of animation or digital video together with textual description resulted in

better understanding than the textual description alone. Moreover, they argued that multimedia could help the learner construct a cognitive model. Kasvi et al [2000] also reported that people supported by multimedia objects (text, pictures and verbal descriptions) completed tasks faster than people who had text only.

3. Authoring a text-based document implies a transformation of complex, unstructured ideas in the mind of the author into a structured, linear sequence of text [Ginige et al, 1995]. A series of illustrations and video clips can speed up the authoring process for describing a long procedural task.

4. Where the task is computer-based, hypermedia allows the links to be embedded within the task [Raybould, 2000], meaning that it enables direct access to the support system from the point where the task is carried out. The impact is that the task and the support system, which were previously physically separated in the conventional support system, can now be integrated which dramatically reduces the time required to locate the support document, as it is embedded within the task.

5. Multimedia, particularly series of pictures or animations, can reduce translation costs. Nieminen et al [1995] reported that a major part of a complex assembly task could be completed without translating textual information into the language understood by the task performers.

Hypermedia systems, used solely for managing information in manufacturing or industrial environment, are often referred to as **industrial hypermedia applications**. In the context of this paper, the word ‘industrial’ refers to the industrial strength hypermedia systems [Malcolm et al, 1991]. They assert that many hypermedia systems have evolved beyond the stand alone applications to become a key technology that integrates various resources across an engineering enterprise, particularly manufacturing and process industries.

An example of the use of hypermedia in industry is an information system to support maintenance (see Figure 1). To repair a machine, a maintenance engineer often has to refer to maintenance manuals, circuit diagrams, mechanical drawings and parts list. At any one time, the engineer requires only a small amount of the information available but needs to cross-reference between several separate documents to find it. With hypermedia, the textual information can be linked to a drawing and, furthermore, a part of the drawing may also be linked to a video showing how to repair that machine.

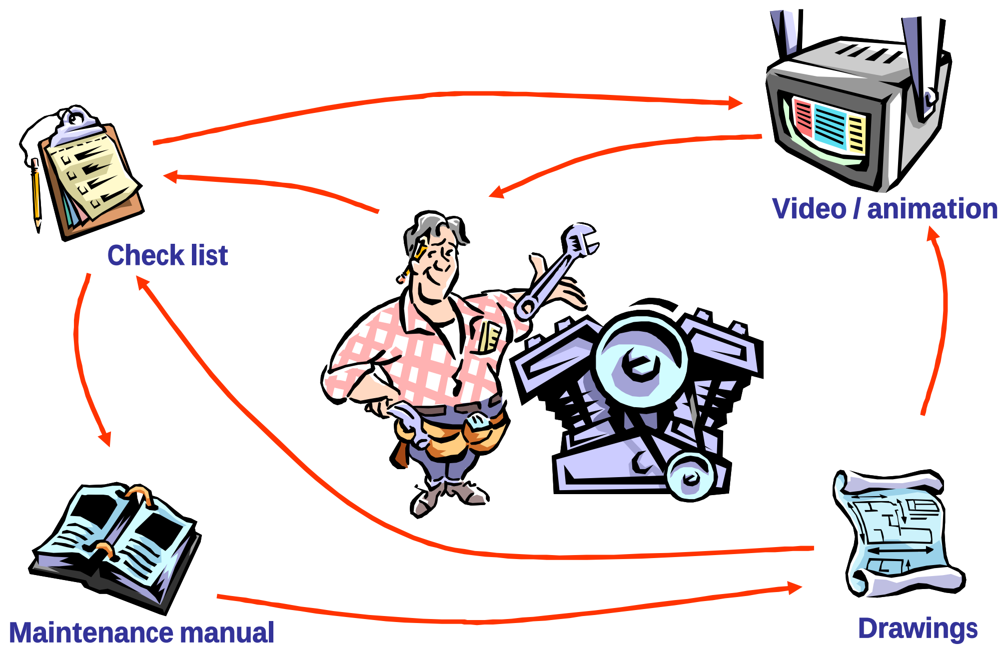

Figure 1 – Hypermedia for maintenance

One characteristic that distinguishes industrial hypermedia applications from conventional, non-industrial hypermedia applications is in their use to support industrial tasks carried out by shop floor workers. Industrial tasks are typically context-specific, procedural, and they require the task performer to interpret a large amount of information in a timely manner. Examples include assembly instructions, troubleshooting guides and maintenance procedures. Understanding the differences between industrial and non-industrial applications is very important because this affects the design of the applications, meaning that one cannot necessarily transfer good practices from the non-industrial sector or vice-versa. For example, although the look and feel may be similar, industrial hypermedia applications should be designed using more detail usability criteria than those in non-industrial applications.

Besides the task, other dimensions such as users, information content/structure, working environment, computing infrastructure and purpose, may often be used to distinguish industrial hypermedia applications from non-industrial hypermedia applications. The information within an industrial hypermedia application is generally more diverse and more task-related than in the non-industrial hypermedia applications. The information is also originated from different sources/domains and a range of file formats, supplied or managed by manufacturing engineers. Additionally, industrial hypermedia applications typically require more sequential navigations, although hypermedia allows non-linear access to information.

Table 1 summarises the differences between industrial and non-industrial hypermedia applications.

Table 1 – Industrial hypermedia vs non-hypermedia applications

	Industrial hypermedia	*Non-industrial hypermedia*
Task	▪ Complex, procedural industrial tasks ▪ Step by step & interdependent ▪ Requires visual inspection and judgement ▪ Maybe time and safety critical ▪ The use of hardware/tool/complex equipment	▪ Less complex, non industrial and typically intellectual tasks ▪ Not necessarily sequential tasks ▪ Less likely to be critical to safety of user
User	▪ Typically shop floor workers with low to moderate computer experience	▪ General users with typically moderate to high computer experience
Content	▪ High level of diversity ▪ Many different information sources and formats ▪ Industrial task-related ▪ Information supplied or managed by task experts	▪ Less diverse information sources and formats
Information structure	▪ Reflects users' mental model of task to avoid disorientation & cognitive overhead ▪ More sequential navigation, less non-linear access	▪ General usability criteria is sufficient ▪ Fewer restrictions, can be purely non-linear access
Environment	▪ Maybe noisy and dirty ▪ May have poor lighting ▪ Workspace may constraint ergonomics ▪ More pressure in obtaining the information from the applications	▪ Less disturbances, e.g. in offices, internet cafés ▪ More attention paid to ergonomics ▪ Less hazardous to users' health and less likelihood of contaminant ingress
Infrastructure	▪ Computers with low to moderate spec ▪ Need more robust system due to more specific purpose ▪ Restricted access privilege ▪ May not guarantee 24/7 support	▪ Usually high spec computers ▪ Freedom to configure software/plug-ins ▪ Easy access to support
Purpose	▪ Setup procedure, troubleshooting guides ▪ As quality documents, governed by legislations/standards	▪ Information retrieval, information archival, e-commerce, entertainment ▪ Less influenced by legislation

3. Innovative Information Management

The concept of innovative information management discussed in this paper is illustrated in Figure 2. Information is populated from different domains or sources and linked together using hypermedia technology to produce a new, structured group of information previously existed in various locations and file/presentation formats. These groups of information will be compiled and presented depending upon the preference of the users, for example base upon the skill levels.

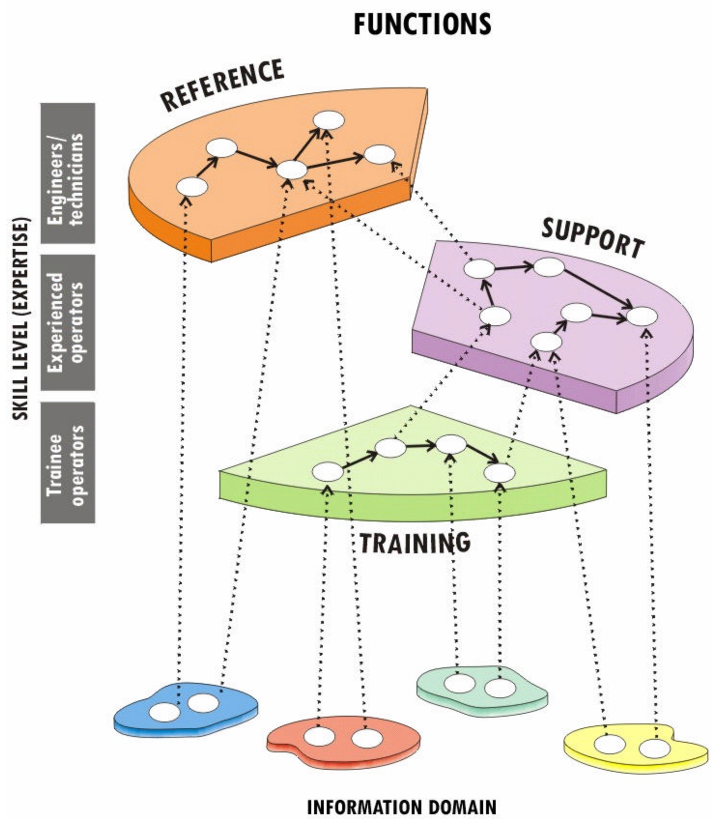

Figure 2 – The concept of innovative information management

In order to demonstrate how the concept can support continuous improvement initiatives, two case studies based upon the two global manufacturers in the UK are presented in the next section.

4. Case study 1: Testing of cellular telecommunication base stations

The company is a global leader in providing integrated communications solutions and embedded electronic solutions. The GSM (Global System for Mobile communication) manufacturing facility in the UK is dedicated to the research, development and manufacture of the GSM products. Manufacturing processes involve the production and assembly of *base transceiver stations*, simply called *base stations* hereafter. These base stations are used to support the infrastructure of the cellular telecommunication networks.

The manufacturing facility consists of a number of assembly lines, starting from the front-end area that mounts the components into the printed circuit boards (PCB) and ending in the systems test area. Due to the pace of developments in telecommunications and electronic fabrication technology, product lead-times are becoming shorter. This has put more pressure on product testing. Since systems test is the last process on the assembly line, a fast and reliable test process is critical to avoid blocking the line and causing late or unreliable deliveries.

The company is obliged by telecommunications standard TL9000 to provide quality assurance by testing the products thoroughly, to prevent defective products being dispatched to the customers. The systems test consists of a functional test and a protection test. The functional test examines whether a base station functions properly whereas the protection test verifies whether a base station can generate error signals for potential problems such as voltage drops and overheating.

The testing process is carried out in a computerised test station shown in Figure 3. Advanced test software running on the test station was developed to automate the testing procedure as much as possible to improve the efficiency of testing process and ultimately to reduce the product lead time. Although the majority of the procedures are under the control of the test software, the overall test process remains labour-intensive. The test software prompts the test operator with instructions to connect the components to the test station, emulating the communication functionality in a cellular network. The successful completion of the test process will therefore depend not only on the accuracy of the test equipment but also on the operators' competence.

As each base station is built to customer specifications, the number of different configurations can be very large, resulting in a more complex and a more time-consuming test procedure. To meet production deadlines, the changeover process from one configuration to another should be fast. Such a system is required to retrieve the configuration number, a unique number for each product variant, which is linked to the configuration diagram showing the connection among the product components, and hence to facilitate a faster changeover between product variants.

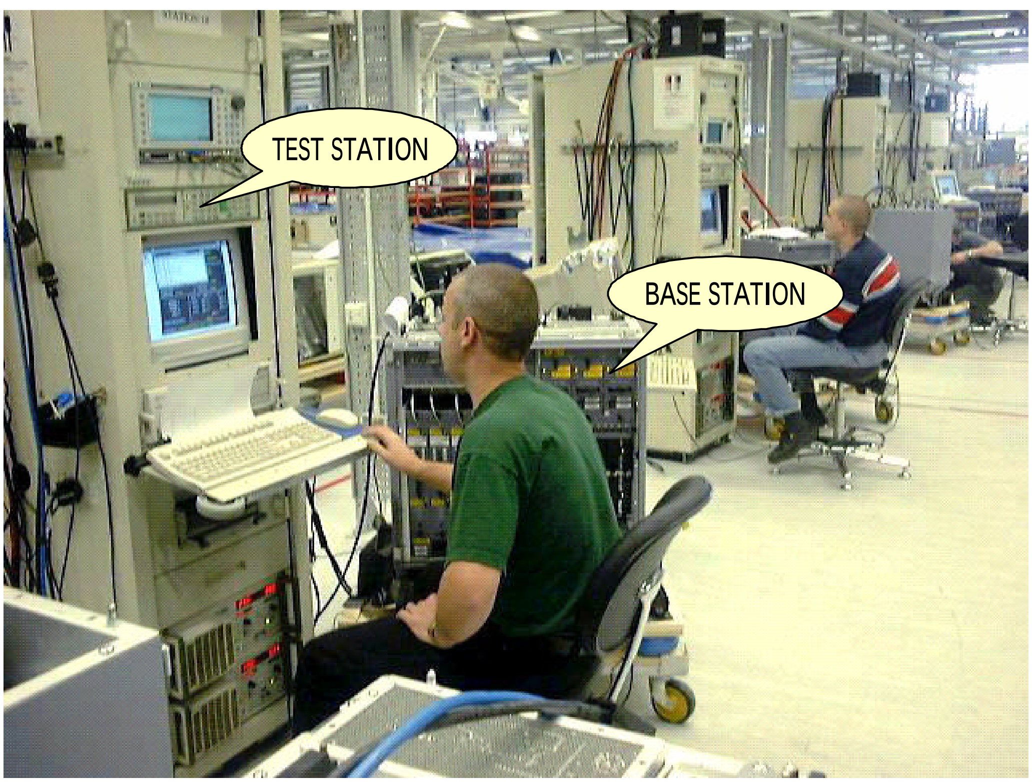

Figure 3 – Systems test area

The company has been continuously seeking innovative ways particularly through the use of information technology to improve efficiency of the testing processes and to enhance productivity of the test personnel. As part of the company's strategic improvement programme, a web-based information system has been developed. The system integrates the current information-base and restructures it into a collection of information that is highly relevant to the task in-hand. With the information integration, it is now possible to:

1. Supply the test personnel, including inexperienced operators, skilled technicians and engineers, with multimedia-based technical manuals that are up-to-date and controlled, delivered when and where needed.

2. Provide an interactive and comprehensive learning environment that can guide new operators to carry out the test process from start to finish with either minimal or no external training.

3. Support the overall training programme within the company by providing an integrated solution enabling trainees to gain a certain level of qualification and to evaluate the effectiveness of the training at the same time.

The system adopts the user-driven approach, allowing the test personnel to explore the system and to select only relevant information about a particular topic of interest. This has encouraged novice users to navigate the system by their own choice of links and using their own methods, at their own pace. To accommodate a wide-range of level of expertise of the users, the system is structured into a number of modules. For the purpose of illustrating the conceptual solutions, only two modules will be discussed in this paper. The modules are called reference and training.

The *reference module* is an electronic manual, consisting of technical information relevant to systems test procedures. The information is structured into sections and each section has smaller sub-sections to allow quick information retrieval. Because of the level of detail and the technical features within the module, it is primarily aimed at technicians and engineers.

The *training module* is a subset of the reference module, allowing less experienced personnel to access the technical materials found in the reference module in a simpler way. Each topic is presented step-by-step, using a predefined access route. Unlike the reference module, the training module is aimed at operators who wish to acquire more technical information regarding the test procedure, which otherwise would require more effort and time to understand, due to the complexity of the technology involved.

The word 'reference' implies that the reference module acts as an online reference library consisting of technical information related to the testing process. For that reason, the structure of the reference module needs to allow the users to determine the sequence of information retrieval that minimised time and effort. The structure is also required to enable the users to predict where the information could be obtained or, if they have accessed the information previously, to recall the location of the information. The latter is crucial when the reference module is used by frequent or more experienced users, who generally need a shortcut rather than a fixed access-route to obtain the same information.

In the training module, diagrams and technical data were omitted and replaced by more user-friendly sentences with less jargon. Whenever necessary, more pictures were provided to explain complex processes, which otherwise would need a large amount of text. Users need to be guided forward and backward sequentially and therefore access structures (for example guided tours) were found suitable for this purpose. At the end of a predefined topic, a direct link to the related topic in the reference module is given, allowing the users to access the same topic in reference module without having to browse through the entire content.

Both the reference and training modules are structured in such a way that they represent an associative relationship between topics of relevance. For example, within the systems test, there are four distinct entities that describe the process, namely the GSM technology, the product (base station), the test station and finally the test procedures. Based on the relationship among these topics, the reference and training modules associate the information from various sources into a logical, structured presentation of information to help the test personnel understand that topic. Figure 4 and Figure 5 show the screenshots of the reference module and training module respectively. Notice the similarity in the way the information is structured.

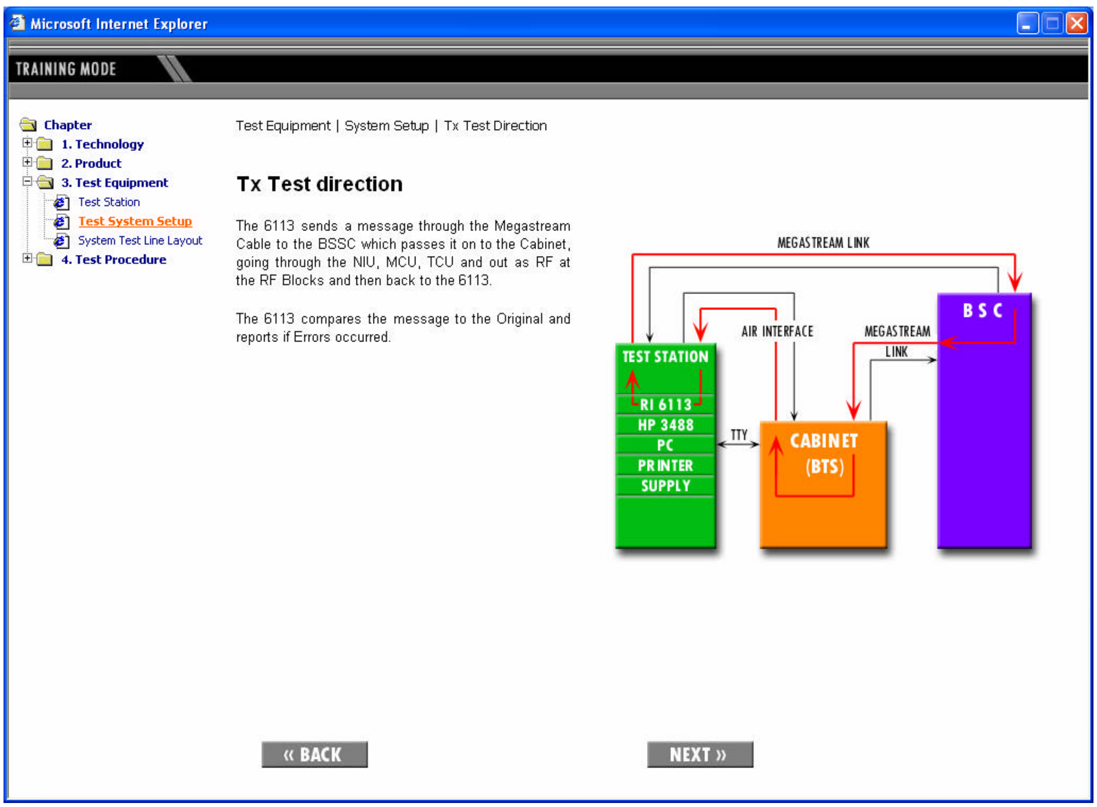

Figure 4 – Training Module

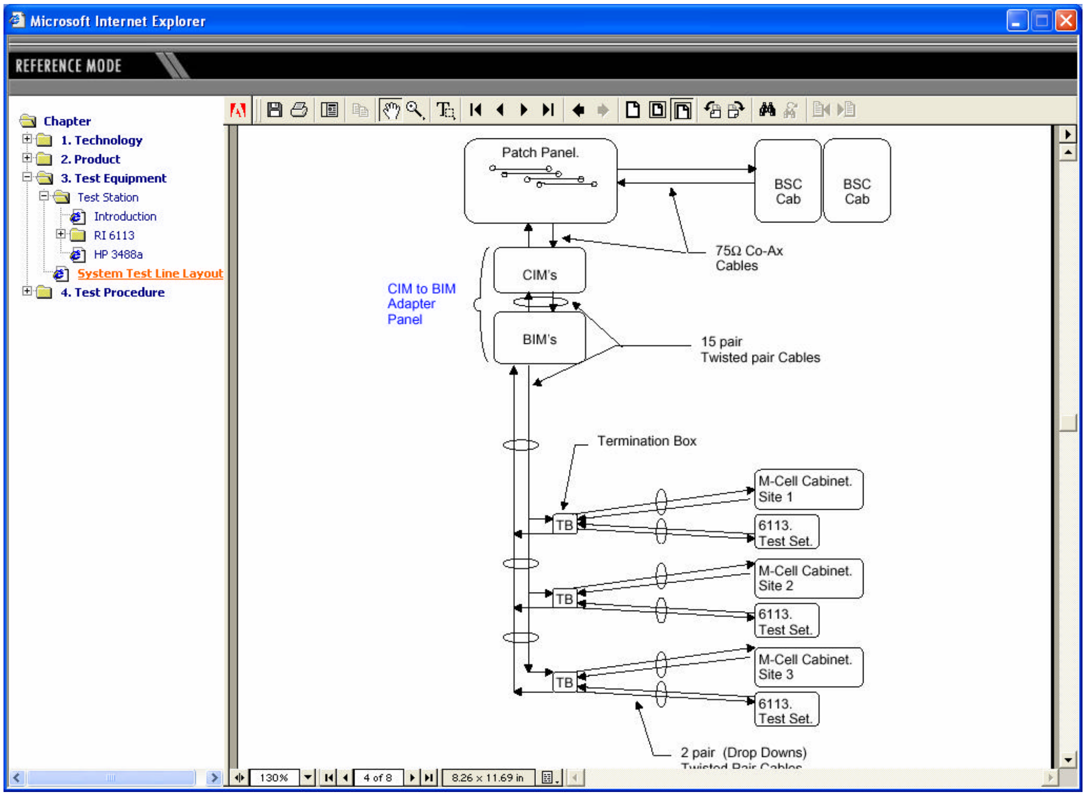

Figure 5 – Reference Module

5. Case study 2: Tool changeover of automated wing assembly machine

The company is the largest European aircraft manufacturer and one of the two most important in the world. The primary role of the UK site chosen for this case study is the manufacture and final assembly of the high-technology wing box structure for all the aircraft models manufactured by the company. The finished products are despatched to the Europe mainland site to be assembled to the fuselage of the aircraft.

In general, aircraft manufacture involves many complex activities whose quality is controlled by documentation. Aircraft factories are also becoming more heavily automated as manufacturers seek to reduce variability and increase efficiency of manufacture. The documentation in use therefore controls not only value adding activities but also activities such as machine set-up, machine maintenance and machine data collection. Traditionally these documents have been supplied in paper-based format, which creates an expensive administrative overhead of revision control. The quality management system must ensure that documents in use are current and that documents that have been superseded are removed from the factory floor. The management of process documentation is described in internationally agreed aerospace standards such as AS9100. Manufacturers can expect to be audited by the FAA or EASA to ensure compliance and there are severe financial penalties for non-compliance.

As well as the possibility of reducing the cost of compliance through electronic documentation, there have been several published studies, such as Solumina (2003), who claims significant performance benefits from the use of such information systems. The main aim of the project discussed in this case study was to investigate, demonstrate and evaluate the use of electronic documents to support shop floor personnel in operation and maintenance of an automated wing riveting machine. The operation is the first stage of the wing assembly, which will rivet upper and lower wing panels, attach stringers to the panels and install both rivets and lock bolts. The machine is shown in Figure 6.

The riveting machines are very complicated to operate and require the operators to carry out a wide range of manual operations. Every fastener and hole is inspected. Position, size, finish and angle are all specified by engineering standards. If a small problem is detected, inspectors can decide the corrective actions. However, if the problem is more serious, the ‘concession’ procedure is initiated. Concession in the context of aircraft assembly refers to as the creation of a detailed record of each non-conformance and the relevant correction, which must be accepted by the aircraft designers. During concession, engineers will look for solutions, test them and calculate their consequences in order to ensure that they do not weaken the panel, and hence the aircraft structure. If no solution can be found, then the wing panel must be scrapped completely. This is a very expensive decision but crucial, because a weak panel can endanger passenger’s lives. Obviously, concessions and scrap have to be minimised.

To avoid deviation from specifications, the riveting process must pass a number of tests before actual operation. These tests are not performed on the wing panels but on pieces of aluminium called test coupons that are representing part of the wing. Test coupons are installed on test stands where the machine drills and rivets them. Once a test is performed, test coupons must be measured (how deep the rivet tails is, how the rivet is expanded in the drilled holes, etc.). These trials and inspections must be carried out every time the tools on the machine are replaced.

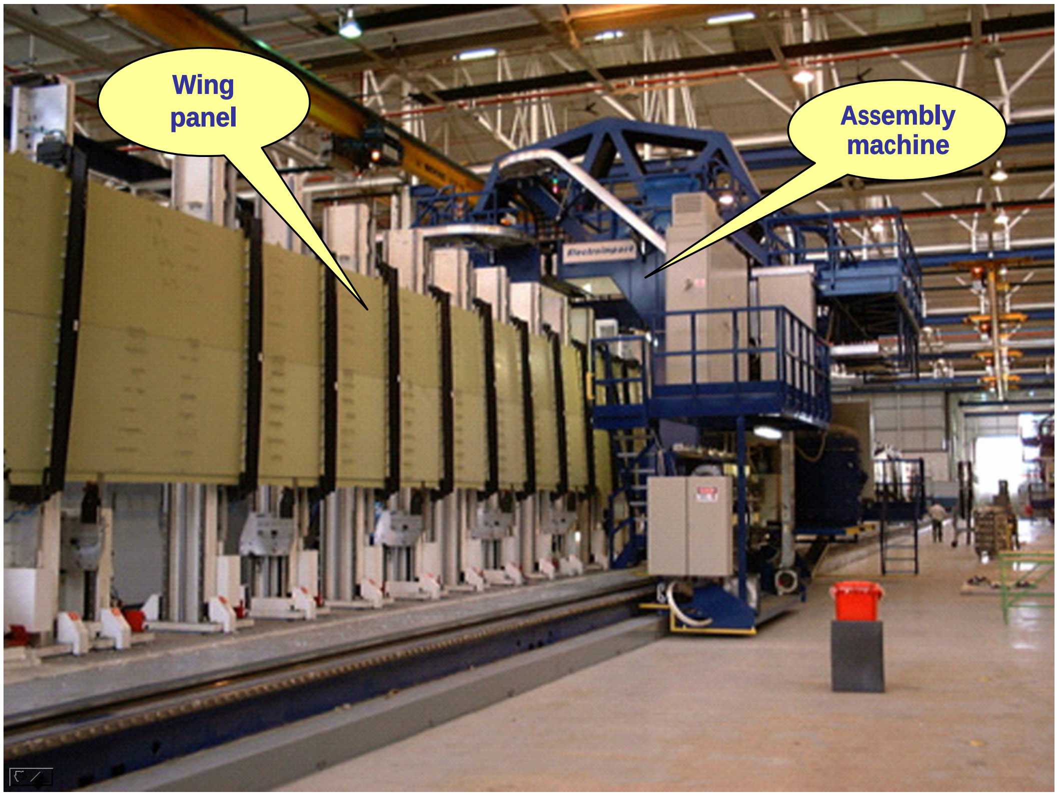

Figure 6 – The automated wing assembly machine

Current procedures for tool changeover and test coupon production are complex and are controlled by paper-based documents. During the tool changeover, the operators have to follow a log sheet instructing them the steps they have to perform and to retrieve the right information related to a particular step, for example the tooling number, the fastener size and the programme number. To do this, the operators have to consult the tooling and programme table in a 57 page paper document. The document itself contains large amount of information, in which only small amount of information that may be needed by the operator at a particular time. It is also cumbersome to use as each page is made up of numbers and references. Some of the information is difficult to control from a quality perspective as it is generated by support staff on the shop floor.

The results are that it is expensive to maintain the quality of the riveting process, the tool changeovers take longer than they need to and some of the efforts of the document writers are wasted as the documents are not fully used by all operators.

Both the machine changeover/set-up procedures and the test coupon documents are based on existing manufacturing instruction documents for each fastener. However, as there is no official document the operators can follow for the programme setup, different operator will do the job differently.

In summary, the operators have to look at many different documents where a large amount of information is available but rarely required. The longer it takes for the operator to retrieve the required information from the documents, the longer the downtime of the machine. This will consequently reduce productivity and increase the cost of ownership of the machine.

To address the above issues, a hypermedia interactive electronic technical manual has been developed. The system aims to support shop floor personnel to carry out tool changeover procedures, machine calibration, test coupon inspection and panel production. The concept of innovative information management was adopted to integrate existing tool changeover guides, check sheet and test coupon procedures and to make these accessible from where the task is carried out. The tool changeover documents and check sheets were turned into a step-by-step guide, enriched with pictures, videos and drawings. A simple database was developed to enhance information retrieval. Manufacturing instructions for test piece production and check sheets were also made multimedia-based, linkable from the changeover guide.

Figure 7 shows a screenshot of hypermedia-based changeover guide consisting of a step-by-step procedure that needs to be undertaken by the operator to replace the tools on the machine. Each step can further be decomposed into a number of sub-steps, as illustrated by the tree menu on the left hand side. Each sub-step is associated with multimedia objects. In this case, (1) textual description of the task, (2) picture of the machine and (3) video clip to show how to carry out the task, as well as (4) tools information, (5) picture of the tool and (6) engineering drawing of the tool. Links to other information, such as tooling number and diameter size of the tool are generated automatically *on-the-fly* by querying the tooling database. With this approach the operator will no longer use the existing paper documents in order to retrieve the required information.

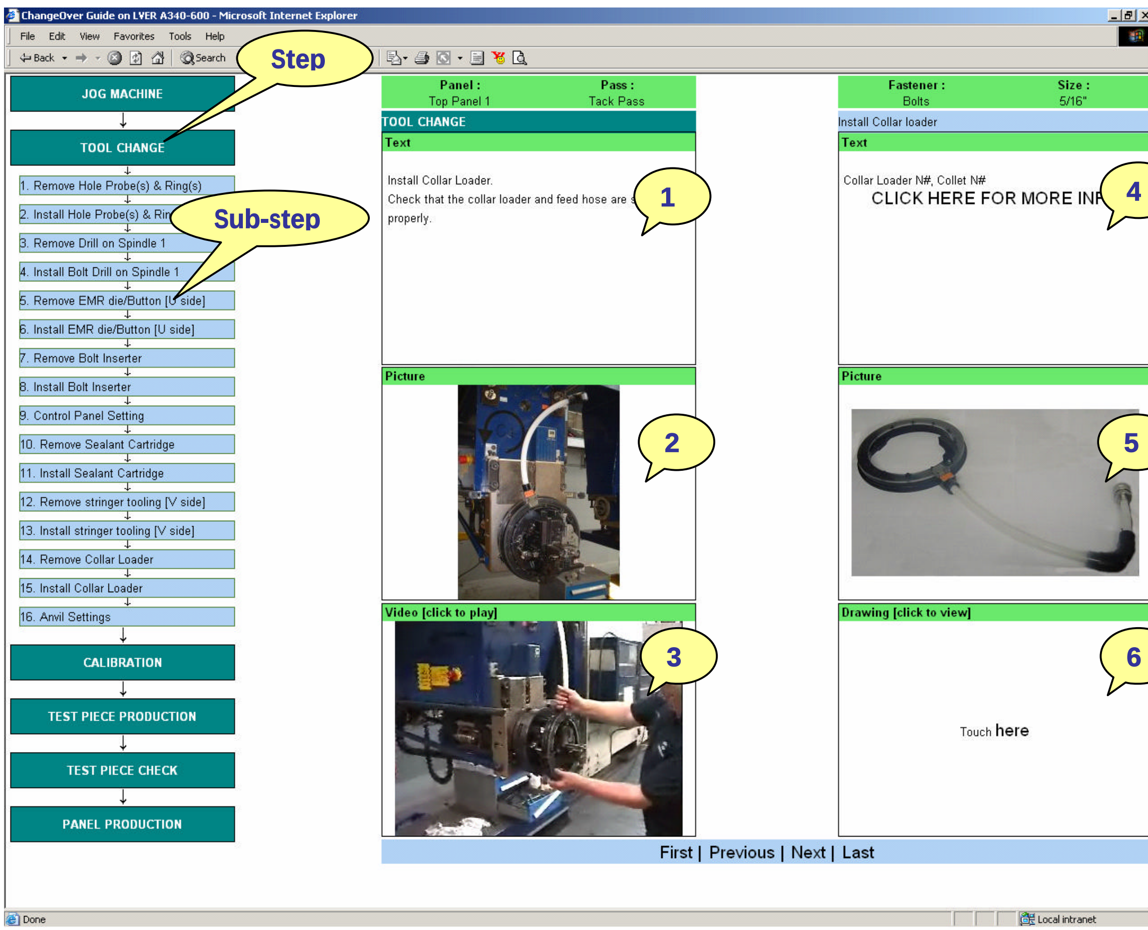

Figure 7 – Screenshot of hypermedia-based changeover guide

6. Lessons learnt for continuous improvements

Many manufacturing information systems, either computer- or paper-based, have followed the traditional approach, in which users can access the information as and when they request, but the efficiency and user-friendliness of these systems are quite poor. This is because allocation of the relevant information in general very much depends on the users' experience and familiarity with the system in use. Until recently this approach was used extensively for stand alone applications. From the user's point of view, the difficulties are associated with information retrieval, accessibility, extensibility and compatibility with other IT tools.

The above case studies illustrate how an information system can be developed to support shop floor personnel to carry out manual, information-intensive tasks. The advances in multimedia and Internet technologies provide a means of improving the situation. In both companies, hypermedia was utilised to develop manufacturing information systems, which aim to provide shop floor personnel with information that is accurate and concise, most relevant to the task at hand, delivered when and where necessary.

The benefits from the adoption of the proposed concept are listed below.

- Hypermedia technology allows information from different domains and formats to be linked together to dynamically construct a new, task-oriented information system, directly accessible from where the task is carried out.
- The innovative information management ensures that information is always available from a centrally managed repository, which reduces costs of content maintenance.
- The adopted concept ensures continuous and consistent transfer of process know-how from the documentation control and management to the shop floor.

- The centralised management of content allows improved control of the documentation systems, one of the necessary criteria for quality assurance.
- The presentation of the information is customised allowing novice users to start using the systems quickly, with little or no training.
- The proposed concept enables information from different domains and sources to be repurposed according to the task it supports. The advantage is improved efficiency of information authoring and delivery to the users.

Without doubt, the concept of information management discussed in the two case studies, offers a new way of empowering shop floor personnel. The systems developed for the two companies can also be used at various levels, both as computer-aided training tools and as interactive systems to help carry out online operations, which assist the shop floor personnel to perform their tasks more quickly and with fewer mistakes.

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