CRANFIELD UNIVERSITY

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An Evaluation of hypermedia information systems support for CNC machinists

SCHOOL OF INDUSTRIAL AND MANUFACTURING SCIENCE

Engineering Doctorate Thesis

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Abstract

As information technology (IT) capabilities increase, manufacturing businesses are realigning their information systems infrastructure to remain competitive. This has resulted in substantial increases in IT use in technical areas of the business. Nevertheless, conventional paper-based information systems are still common at the shopfloor. Hence, manufacturers need to understand whether there is any benefit in extending IT functionality to the shopfloor.

The focus of this research is the support of the CNC machinist, who has a specific set of craft skills and knowledge that are a core business capability in the metal cutting industry. By evaluating the impact of hypermedia information systems upon the independent decision-making and communication capabilities of CNC machinists, this research aims to provide an understanding of the shopfloor performance benefits of replacing existing paper-based systems with this relatively new technology.

This research finds that in CNC machining environments where there are limited divisions of labour, hypermedia-based manufacturing instructions support CNC machinist independent decision-making and cross-boundary communications as effective as paper-based manufacturing instructions. CNC machinists also demonstrate an acceptance of the new technology. Hence, the sponsor and the research community can pursue continued research to develop the technical *and* social systems to achieve predicted business benefits.

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This thesis is dedicated to my Mum.

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1 Introduction

1.1 Information systems for CNC machinists

This thesis evaluates the impact of information systems on the role of CNC machinists. The research process included the evaluation of a prototype information system developed to provide support for CNC machinists' independent decision-making and cross-boundary communication. The core research activity was conducted at the sponsoring company, Rolls-Royce plc, to meet the requirements of the Engineering Doctorate qualification. The research findings are, however, considered relevant to CNC machinists in other manufacturing organisations.

1.2 Introduction to the Engineering Doctorate

The Engineering Doctorate (EngD) Scheme was established in 1992 by the Engineering and Physical Sciences Research Council (EPSRC). The EngD provides research engineers with the technical, business and personal development competencies needed to reach senior management positions early in their career (EPSRC, 2003).

The EngD spans four years on a full-time basis. Knowledge and skills obtained from taught courses are applied to a doctoral level industrial research project in collaboration with industry (EPSRC, 2003). In the case of the Cranfield Engineering Doctorate, the taught modules comprise management related and specialist engineering topics. Management modules are provided by the first year of the Cranfield Executive MBA and specific engineering courses are offered by relevant schools. The Cranfield Engineering Doctorate Centre was established in 1993.

EPSRC define the aims of the Engineering Doctorate as:

- To provide research engineers with experience of rigorous, leading edge research in a business context;

- To develop competencies that equip research engineers for a range of roles in industry;
- To provide a mechanism and framework for high quality collaboration between academic groups and a range of companies;
- To contribute to the body of knowledge on a particular technical discipline, industrial sector or multidisciplinary theme (EPSRC, 2003).

Additionally, EPSRC state: "The training provided should be flexible and should evolve in line with the emerging needs of the individual and industry. The training must be of high quality and auditable. The Engineering Doctorate should be at least equivalent to the intellectual challenge of a PhD, but enhanced by the provision of taught material in both management and technical areas. It is designed to increase those skills and competencies required by industry."

1.3 Introduction to Rolls-Royce plc

Rolls-Royce plc is a global company with a competitive range of gas turbine products and services. As stated in the group's 2002 annual report, Rolls-Royce's market position is number 1 in both the marine and energy gas turbine markets, and number 2 in civil aerospace and defence (Rolls-Royce, 2003). In 2002, Rolls-Royce operated in 48 countries with 37,000 employees. Group turnover for 2002 was £5,788m, with an underlying profit of £255m and an order book valued at £17.1bn. In 2002, Rolls-Royce had 54,000 gas turbines in service.

Since October 2001, Rolls-Royce has resized the business to balance load and capacity to improve delivery, leadtime and cost. In 2002, working capital reduced as a proportion of sales from 10.5% to 6.8%. This resulted from SAP[1] implementation, supply chain restructuring and headcount reduction. Meanwhile, the group has made significant knowledge-based investments in

[1] SAP is an enterprise resource planning (ERP) package.

technology, product, capability and capacity to gain market position and to access long term global markets. Equally, Rolls-Royce is well placed to manage short term uncertainty (Rolls-Royce, 2003).

In the next decade, the group will focus expenditure on technology acquisition. New product development has slowed in line with demand. Hence, Rolls-Royce's operational focus will be on unit cost reduction, development of derivatives, improved in-service operation and the creation of capabilities that increase the scope and value of service activities. In 2003, priority is given to the management of uncertainty, and continued refinement of the information technology platform to ensure that it is an effective and affordable enabler (Rolls-Royce, 2003).

1.3.1 The relevance of this research to the business

To meet its strategic objectives, Rolls-Royce will continue to realign its structure and invest in effective systems. As stated, Rolls-Royce recognises the value of creating new competences and the need for an effective and efficient information infrastructure. With the implementation of improved information systems within the technical community[2] and therefore increased capabilities, it was recognised that shopfloor information systems should be evaluated to identify scope for improvement in order to realign production with the technical community. In particular it was identified that manufacturing instructions, or "the technical package"[3], are currently delivered via dated information systems. Hence, Rolls-Royce identified the need to evaluate existing shopfloor information systems and to research alternative solutions that better meet their strategic objectives.

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[2] The technical community is the term used within Rolls-Royce to describe office and laboratory-based engineering and scientific functions.

[3] The technical package is the term used for a set of manufacturing instructions, such as engineering drawings and part programs. The convention is to deliver the different information as a single 'package'. This is discussed in chapter 5.

1.4 Scope of the research

Rolls-Royce employs many manufacturing processes, the most common of which is CNC (computer numerical control) machining. The widespread employment of CNC machining across the organisation identifies it as a core capability and therefore the chosen subject for improvement of the associated manufacturing instructions. Hence, it is considered necessary to briefly explain what CNC machining is and why its continued improvement is important to the sponsor.

1.4.1 CNC machining

The Second World War brought rapid development of military and commercial products. The levels of automation and accuracy required to manufacture such products could not be achieved by the labour intensive machines of the time (Smith, 1993). Hence, the world's first numerical controlled (NC) machine tool was developed and demonstrated at the Massachusetts Institute of Technology (MIT) in 1952 (Childs, 1969). The principle of numerical control, as demonstrated in 1952, is the electronic conversion of coded information into machine tool instructions (Childs, 1969). Early NC machine tools read information from tapes or punched cards. This was then translated into movement of the machine tool table and/or head via electronically controlled leadscrews.[4]

The mid-1970s saw "revolutionary advancement" of machine tool controllers with the advent of computer numerical control (CNC) (Smith, 1993), where tape and card information were replaced with computer-based information. Today CNC machine tool functionality has advanced much further. Integrated computer systems, multi-axis geometry, cutting tool libraries and interchangeable machine beds are just some of the features utilised by CNC machining centres to process complete components in a single operation.

[4] For a detailed explanation of numerical control and associated terminology, refer to Childs (1969).

The benefits of CNC greatly exceed those of conventional machining. The relatively high capital expenditure is therefore acceptable because payback is swift (Smith, 1993). Smith discusses the advantages of investment in CNC as being:

- CNC machine tools offer *increased productive throughput*. By employing high traverse rates and automatic tool changing, machine idle time is significantly reduced.

- Process *leadtimes are reduced* as set-up time is minimised by the automation of part loading and datum location. Thus batch sizes can be reduced, enabling an economic batch size of one and thereby reduced work in progress.

- The storage and retrieval of the part program also contributes to substantial reductions in leadtime, and enables the retention of invaluable knowledge.

- CNC facilitates confident prediction of the *accuracy and repeatability* of dimensional characteristics. Hence, scrap and rework are virtually eliminated to reduce inspection, assembly and fitting costs.

Smith (1993) also cites the following ancillary benefits: precise processing of component modifications with minimal production disruption; improved planning and scheduling; repeat orders are easily undertaken; and tooling is reduced. The cost benefit of CNC is illustrated in figure 1.1.

Hence, the resultant implementation of CNC across the metal cutting industry has resulted in conventional machine tools being restricted to limited applications. Indeed, in many factories, the conventional machine tool has become obsolete.

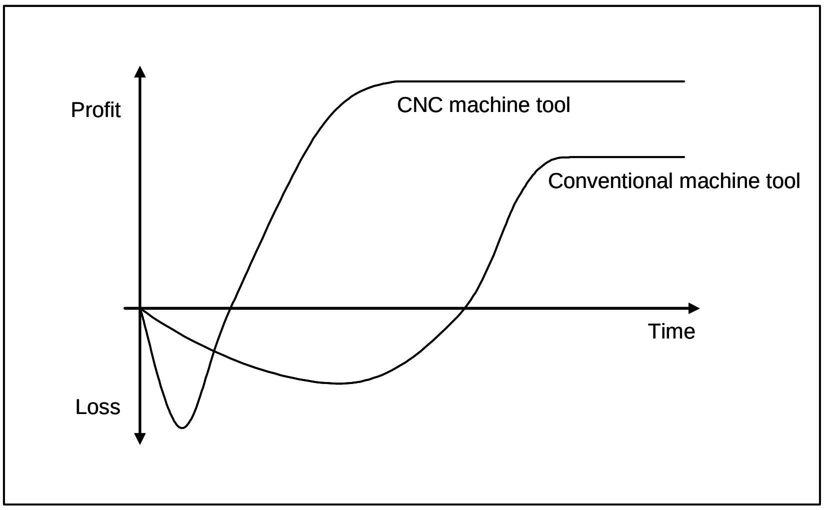

Figure 1.1 Theoretical operating profit over time of machine tool investments (after Smith, 1993)

1.4.2 CNC machinists

Rolls-Royce enjoys the benefits of CNC machine tool use listed in the previous section. In line with corporate strategy, the group will seek further benefit from improving this core capability. As stated, a need to improve the associated manufacturing instructions has also been identified. However, a further factor must be considered – the CNC machinist.

The CNC machinist's role is explored in chapter 2; however, in general terms, it is evident that as operators of the machining process and users of related information, they will be impacted by any improvement activities. Their adjustment to change and subsequent system use will consequently influence manufacturing performance. Hence, an evaluation of the human aspects of potential changes to the information systems used is required. The research findings will therefore enable the sponsor to assess the scope for technical package improvement and the impact upon user performance. This assessment could then lead to further strategic and structural realignment. The position of this research in relation to the sponsor's strategy is illustrated in figure 1.2.

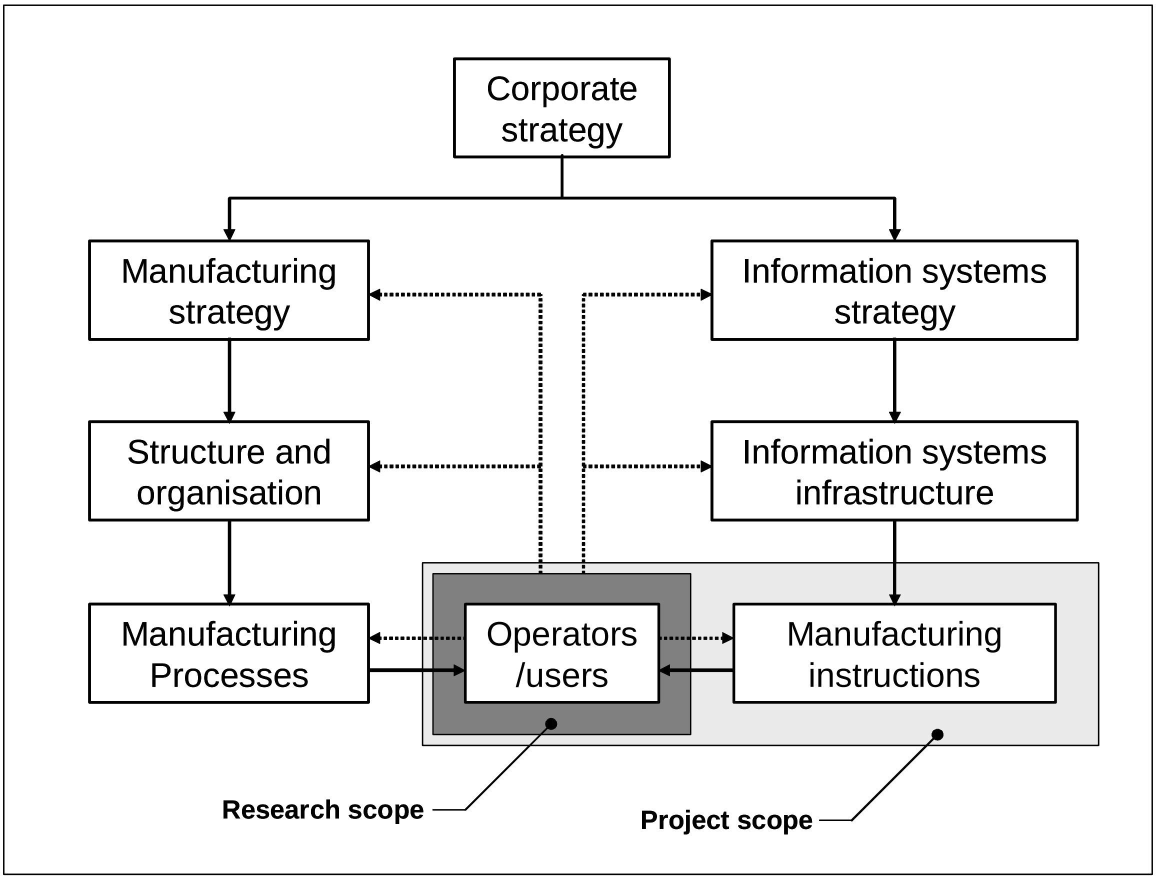

Figure 1.2 Scope of the research

1.5 Research question

The research scope is defined in line with the strategic aims of the business. In chapters 2 and 3, a comprehensive literature review narrows the focus of the project to clearly define the area of research. To enable transition from the potentially broad project scope and a narrow research focus, a generic research question is defined.

How can information systems support CNC machinists?

This question directs the literature search and enables consistency throughout the thesis.

1.6 Thesis structure

Chapter 1: This chapter introduces the purpose and scope of this research.

Chapter 2: To narrow the focus of the research, a literature review was conducted. Chapter 2 explores the influences upon the role of CNC machinists in manufacturing to identify where further research is necessary.

Chapter 3: A review of the use of information systems in CNC manufacturing further narrows the research focus. A gap in the current body of knowledge is identified from the conclusions of chapters 2 and 3.

Chapter 4: Based upon the findings of the literature review, research hypotheses are presented. A discussion of the selection of an appropriate research methodology follows to modify and test the research hypotheses.

Chapter 5: The results of the core research activity are presented to provide an evaluation of existing and prototype information systems support for CNC machinists at that research setting.

Chapter 6: Case studies are discussed to validate the preliminary research findings.

Chapter 7: The overall research findings are discussed to identify a contribution to the wider body of knowledge and to state the implications of this research to the research sponsor. Recommendations for further research are also made.

2 CNC machinists

2.1 Introduction

This chapter aims to present what is understood about CNC machinists, the influences upon their behaviour and the environments in which they work. Chapter 3 narrows the research focus further by exploring the use of information systems in such environments to identify a gap in the knowledge.

2.2 Conventional machinists and CNC machinists

Manufacturers have a choice of several machine tool designs to perform different types of operation. Conventionally, this necessitated training or employing machine tool operators with varying degrees of skill, as the productivity and quality of machining operations were to a large extent governed by the operators themselves (Wilkinson, 1983; Hazlehurst, et al., 1969). However, since the advent of numerical control, machine tools have been designed for versatility (Smith, 1993). Thus, one multi-axis CNC machining centre can now perform a series of operations that once required an entire machine shop (Smith, 1993). This has had a twofold impact on machinists: new skill requirements (Hazlehurst, et al., 1969) and a dramatic change in labour requirements (Williams & Williams, 1964). The second impact is addressed later in this chapter.

Existing classifications of machinists confirm that several skill levels were once required (Taylor, 1978; Genevro & Heineman, 1991). Today machinists can be broadly classified as either *skilled* or *semi-skilled* (Genevro & Heineman, 1991). Taylor (1978) provides a succinct discussion of these two groups, which is summarised below:

- *Skilled machinists* commonly learn their trade through years of training in the form of an apprenticeship, where skills are passed from worker to worker. A skilled operator is able to plan and execute the processing of a component by interpreting the engineering drawing provided and selecting the most effective machine tool parameters to produce a quality component within the timescale required.

- *A semi-skilled machinist* trains for a limited period of weeks and is capable of only a fraction of the skilled operator's tasks. Semi-skilled machinists conventionally operated semi-automatic machine tools such as capstan lathes, developed to reduce process times by reducing manual input. Machine *setters* are employed to set the necessary machine tool parameters for the semi-skilled operators. Setters are skilled machinists. However, these machine tools, and therefore semi-skilled operators and setters are now scarce since the advent of CNC. Semi-skilled operators are today more likely to be employed at CNC machines with long production runs of established products with well proven programs.

In contrast with these two classifications, CNC machinists can be viewed from different perspectives. CNC machine tools automate the process of machining by representing the planning and execution tasks in a computer program (Taylor, 1978). The program is downloaded to the machine tool, checked by the operator and run. Thus, as Taylor (1978) states "it might seem that the *(CNC)* operator would need to be skilled in work-holding methods and nothing else". Equally, Wilkinson (1983) argues that a CNC machinist may indeed become merely a "machine minder".

Nevertheless, a CNC machinist is required to be conversant with both the operation of the machine tool and the programming language to prevent process error and to optimise tool use. Hazlehurst, et al. (1969) provide an empirical comparison of the skills required of both conventional and NC machinists.[5] Four types of skill were studied:

1. *Motor skills*. Within the context of machine tool operation, motor skills include:

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[5] At the time of publication of that paper, CNC was not commercially available.

- small delicate movements, especially fine finger work (e.g. using a micrometer);
- rapid highly dextrous movements requiring co-ordination (e.g. using both hands on machine controls);
- steady controlled arm movement (e.g. hand feeding a cutting tool).

2. *Perceptual skills*. These consist of sensing, measuring and judging. Hazlehurst, et al. note that the number of machine controls and information sources, and the complexity and frequency of their use create different perceptual loads. Examples include:

- the monitoring of sounds, vibrations and other signals that indicate how the process is running;
- visual and tactile discrimination to judge surface finish or cutting tool sharpness.

3. *Conceptual skills*. These skills are concerned with abstracting, calculating and inferring. Within the context of machine tool operation, conceptual skills include:

- understanding and translating abstract, symbolic information in the form of drawings, layouts planning sheets, programs, etc.;
- making calculations to establish co-ordinate and datum dimensions from complex drawings.

4. *Discretionary skills*. This skill set includes decision-making, independent action and resourcefulness. Hazlehurst, et al. state that the extent of discretionary skills use may be related to the amount of control an operator has over the machine. In machine tool operation, dimensional accuracy, surface finish and metal removal rate are influenced by operator discretion. Discretionary skills include:

- Ensuring efficient (tool) location;

- Decisions about tools, speeds and feeds, and sequence of operations;
- Improvising a setup.

With respect to NC machine tool operation, Hazlehurst, et al. (1969) find:

- Reduced demand for motor skills;
- Increased demand for perceptual skills;
- Increased demand for conceptual skills;
- A reduction in the number of decisions required of an operator.

They therefore conclude that conventional operators commonly have the required skills for NC machining. Additional training is therefore recommended to learn programming skills.

More recently, multi-axis CNC machine tools have extended the need for yet more perceptual and conceptual skills (Genevro & Heineman, 1991). Consequently, in some environments, machinists are now required to be highly skilled and can operate both CNC and conventional machine tools of varying designs. Hence, apprentice machinists still undergo extensive training to attain the requisite theoretical knowledge that enables them to plan work sequences, perform computations and to select and use measuring tools (Genevro & Heineman, 1991). The result is a highly skilled and versatile machine tool operator.

From a psychological standpoint, Böhle, et al. (1994) confirm that skilled CNC machinists must possess a practical ability, to complement specialised know-how and theoretical knowledge. A component of this is tacit or experiential knowledge. Böhle, et al. (1994) find examples of experiential knowledge to be: a feeling for materials and machines, an orientation from the noise of the machining operation, an improvisational-experiential way of coping with malfunctions, and intuition.

2.3 Alternative perspectives of CNC and the CNC machinist

From a technological perspective, the benefits of CNC are evident.[6] However, relatively swift technological advances have led to equally swift changes in the labour requirements of the metal cutting industry. This, combined with the changing economic, political and social landscape, has contributed to the factory environments seen today. Different perspectives of the impact of technology implementation and organisational practices are discussed to understand the foundations of the subsequently reviewed literature.

2.3.1 Generic perspectives of Industry

In the 19th century, Karl Marx came to the conclusion that the advancement of industry via the development of "labour-saving devices" could only result in "antagonism between capital and labour" (Benson & Lloyd, 1983). Marx saw that demand for consumer goods came from workers; but with fewer workers, demand would reduce, leading to economic depression. This central tenet of socialism (Benson & Lloyd, 1983) has to some extent been proven by global economic history.

Long term cyclical change within industry has shaped the "labour movement" (Benson & Lloyd, 1983). The introductions of first steam power, then railroads, and latterly electricity and the automobile, followed by electronics have served to periodically unbalance workforce dynamics by changing the way we work.[7] Hence, in each instance, the existing "framework of economic security" was undermined, but provided new opportunities. Thus, new technology introduction provides employers with economic strength and reduces employee bargaining power (Benson & Lloyd, 1983). A Marxist would typically describe this as capital increasing in power over labour (Wilkinson, 1983).

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[6] See Chapter 1.

[7] Benson & Lloyd (1983) offer an explanation of economic wave theory, which underpins this discussion.

Throughout the 20th century, social theory evolved as economic conditions changed. Rose (1978) cites five principle stages of industrial theory development during this time. From the turn of the century, Scientific Management (Taylor, 1911) dominated industrial thinking. Frederick Taylor considered managers to be incompetent and workers to be motivated solely by financial reward. The introduction of the "scientific manager" sought to eradicate inefficiency in the workplace by simplifying work tasks (Taylor, 1911). Sociologically, the impact of Taylorism created new work structures that are viewed both positively and negatively. As new work tasks were created, new jobs emerged (Rose, 1978). However, new labour divisions resulted (Braverman, 1974). Knowledge had previously been retained on the shopfloor as workers trained extensively to gain the craft skills[8] necessary for complex tasks. By simplifying these tasks, Taylor took that knowledge and gave it to the newly created scientific manager, and with it went the power (Braverman, 1974).

Meanwhile, another school of thought gained momentum during wartime. The 'human factors industrial psychologists' viewed workers as "complex organisms" (Rose, 1978). Studies of fatigue and monotony led to the recognition that due to worker shortages, people were working excessive hours for the First World War effort. The increasing influence of the emerging trade union movement forced Western democracies to reduce working hours (Benson & Lloyd, 1983).

During the 1930s, the third phase of social theory development, 'human relations theory', saw that society as a whole influences industrial behaviour. The perceived "irrationalism" of workers and their "moral dependence upon management" was thought to have two causes. At a direct level, 'work groups' were seen to constrain worker behaviour based on their role and status within a group. Indirectly, the "shaky social fabric" of the time was uncomfortable and

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[8] Craft skills are those skills acquired from lengthy apprenticeships, passed on from man to boy. This has been the case for many trades throughout history.

workers eased this by creating informal organisations in the workplace (Rose, 1978). This is, however, considered by modern sociologists to be a poor body of work.

By the 1950s, ‘technological implications social theory’ came to the fore. This theory determined that technology does not directly influence industrial behaviour, but is a variable of that behaviour (Rose, 1978). Hence, an organisation modifies its methods and relationships to achieve a strategic fit.

The 1960s saw the advent of ‘Actionalism’, where the worker is viewed as being passive; merely responding to his/her physical or technical surroundings. Unlike human relations theory, society’s influence is viewed positively, considering social motivations and aims. Thus the “work community nexus” is used to explain worker behaviour; the most prevalent example of which is “the American Dream” (Rose, 1978).

With perhaps the exception of human relations theory, these social theories continue to influence the development of industrial work structures. As industrial technology and organisation have advanced, workers have continually faced change. Thus, even before considering the direct impact of CNC, it is clear that machinists, as with all factory workers, have inherent behaviours influenced by successive applications of new technologies and methods.

2.3.2 Perspectives of the CNC machinist

The influence of microelectronics upon industry is vast. As the size and cost of electronics have reduced, the range of processes that can be automated has increased (Wilkinson, 1983). Fundamentally, the spread of automated processes resulted in a dramatic reduction in shopfloor labour requirements. Meanwhile, a new role emerged, that of the NC or CNC programmer[9]

[9] A programmer is required to, at the very least, write the requisite NC program. Thus he/she performs many of the tasks that machinists were conventionally accountable for. It is often the case that a programmer will have once trained as a machine operator or as a technician.

(Wilkinson, 1983), as work structures adapted to the new technology (Lundgren, 1969; Williams & Williams, 1964). Wilkinson reports the impact of such widespread change to be a demarcation between operators and programmers. Equally, divisions formed between programmers and planners.[10] Two bodies of work explain this phenomenon.

The ‘innovation approach’ to new technology determines that as an innovation is diffused, firms must adopt it to remain competitive (Wilkinson, 1983). Thus a sociological impact is seen. Wilkinson (1983) cites Touraine’s study of the impact of automation,[11] which determined that an “adjustment problem” arises from the transition from craft skills to technical skills. This research observed better working conditions for operators, and reduced effort. However, boredom was a problem, which led to disruption of workgroup dynamics. To compensate, worker adjustment techniques and manager adaptation were recommended (Wilkinson, 1983).

Braverman views automation less positively. The impact of scientific management is central to Braverman’s argument. By reducing labour’s craft status to a series of simple tasks, workers are “homogenised” (Wilkinson, 1983). Mental tasks are separated from manual tasks, handing the knowledge to management. The result of this is cheap labour and reduced production variability, as the pace and quality of work is dictated by management (Wilkinson, 1983). This is the foundation of the deskilling hypothesis. Braverman (1974) sees two ways to deskill the workforce: organise and automate. Thus, the adoption of numerical control and the subsequent reorganisation of work structures are commonly viewed as the deskilling of machinists. Braverman views the transfer of skills to the office as the reduction of a shopfloor operator to an on/off switch (Wilkinson, 1983).

[10] A planner is an engineer responsible for the planning of processes. The programmer has, therefore, also taken some of the conventional tasks of the planner.

[11] Wilkinson (1983) states that Touraine’s work is published only in French. The summarised citation is therefore considered sufficient.

Wilkinson (1983) does however present flaws in Braverman's argument. Braverman sees labour as unproblematic and acquiescent; and that Taylorism is fundamental to work organisations. This is not the case (Wilkinson, 1983). Braverman's strongest critics are, in fact, fellow Marxists. Wilkinson summarises the common critique as being that workers can indeed "shape" work place relationships, and management have a choice in what they implement. Thus, deskilling is only one possible outcome.

Many more recent authors also take an objective view of deskilling. In Form's view (1987) skill correlates with job complexity. He therefore concludes that deskilling is not a result of numerical control, but a result of large scale batch production. However, this does revert back to Braverman's point that deskilling results from re-organisation as well as from automation, where batch production is in many respects dependant upon organisation.

Meanwhile, case studies of new technology introduction and associated re-organisation have observed mixed reactions to it. Davids and Martin (1992) report that some employees embraced advanced manufacturing technology (AMT), whilst others feared it. Similarly, Agnew, et al. (1997) viewed a computer integrated manufacturing (CIM) system implementation to result in a Tayloristic work organisation and a degradation of work. Finally, Zicklin (1987) provides empirical data which suggest that NC technology does influence the skill level and the skill mix within a factory. The data do not however support the deskilling hypothesis.

Thus, whilst the deskilling hypothesis is considered to neglect certain facts, it is not conclusively disproved. Management who implement new technologies and re-organisations without consideration of skill requirements must therefore beware the consequences.

2.4 Management choice

Wilkinson (1983) presents two views of automation from two different manufacturing sectors – continuous process production and the engineering industry. In the process industry, automation has been seen to create democratic work structures and autonomy; whilst in the engineering industry more centralised control, supervision and specialisation are a result. It would therefore appear that management have a choice of the level of automation employed and the associated organisational structure. Yet, aerospace manufacturers are governed by Federal Aviation Regulations (FAR) 14 Code of Federal Regulations (CFR) Part 21, which ensure in-service aircraft safety. Hence, the aerospace sector's process choices are limited to some extent by regulatory controls.

Strategic choice of work structures is agreed to be a paramount consideration in modern factories (Linstrum, 1991; Kidd, 1988; Hirsch-Kreinsen, 1993). Linstrum (1991) views automation to be replacing operators' knowledge and experience, to reduce cognitive decision-making. Linstrum therefore considers that managers must decide whether to contribute to "workforce obsolescence or to empower them". The danger of not building skill into a job would be, at best, workforce discontent, and, at worst, rejection of the production system (Linstrum, 1991). Both Kidd and Hirsch-Kreinsen expand this argument by identifying three available choices. They do however present different perspectives.

Kidd (1988) takes a socio-technical viewpoint of the choices available to CNC machine shop management. Kidd finds one choice to be to automate where possible and offer only those tasks that cannot be automated to workers. Agreeing with Linstrum, Kidd finds that this choice would neglect any organisational and interface considerations. Kidd's second choice is to build ergonomic and job design principles into those tasks performed by operators, thereby offering a better quality of working life. His third and final consideration is to use social, technical and economic considerations to shape the automated technology and evolve new skills. Thus, based on which choice is made, automation can either assist man or replace him (Kidd, 1988). As with many of the authors previously discussed, Kidd identifies the extent of scientific management to be the main determinant of whether a shopfloor work structure will tend towards a decrease or an increase of the skill requirement.

Hirsch-Kreinsen (1993) presents diagrams of the 3 strategic choice outcomes. Figure 2.1 represents an organisation where the shopfloor is subordinate to a central planning and control function (i.e. extensive divisions of labour exist). Figure 2.2 illustrates a firm that also has central planning and control, but workers tasks are not differentiated (i.e. limited divisions of labour exist). This organisation is common where complex components are produced and where short production runs are necessary. Finally, figure 2.3 illustrates an organisation with control at the shopfloor to achieve production flexibility (i.e. production islands exist). It is most commonly seen as a specialist section within a machine shop.

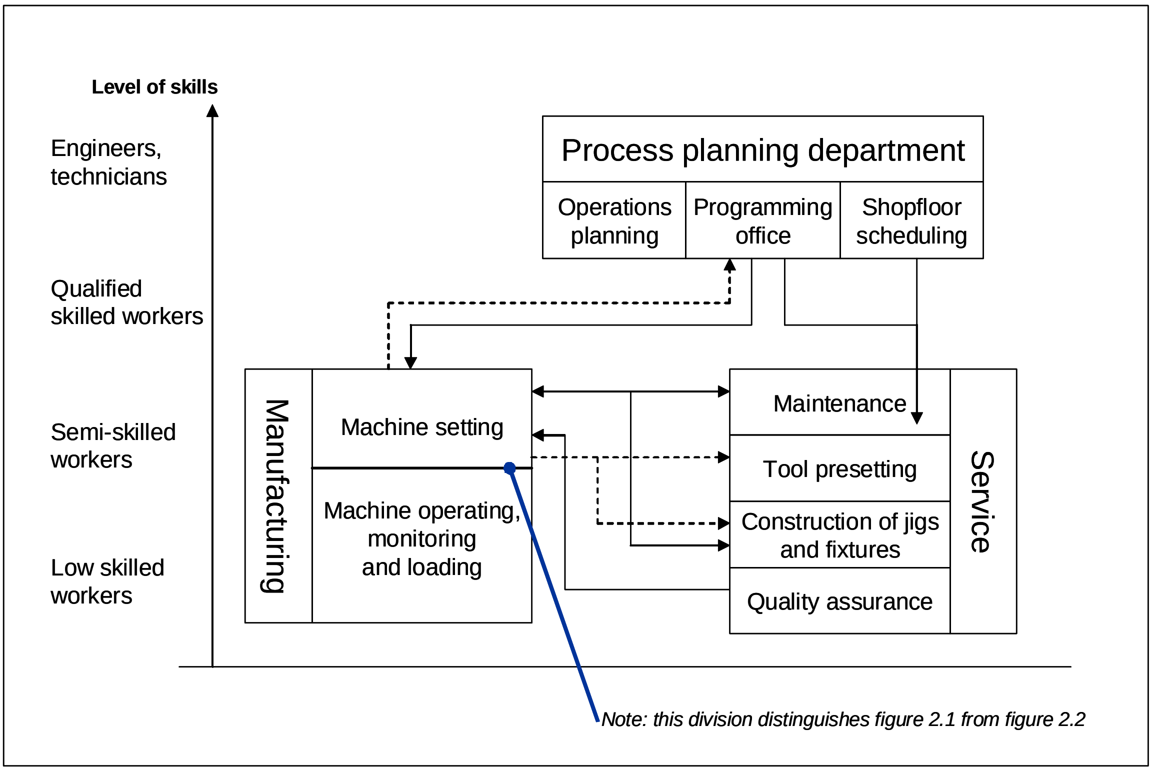

Figure 2.1 NC organisation: extensive division of labour (after Hirsch-Kreinsen, 1993)

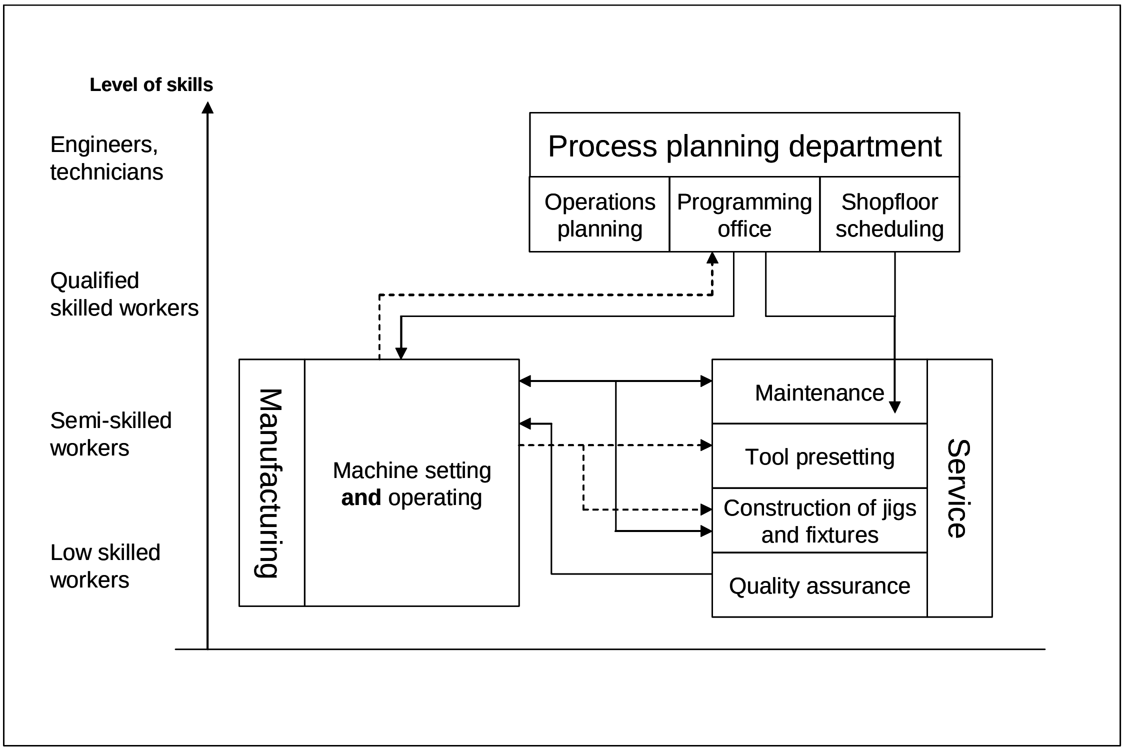

Figure 2.2 NC organisation: limited division of labour (after Hirsch-Kreinsen, 1993)

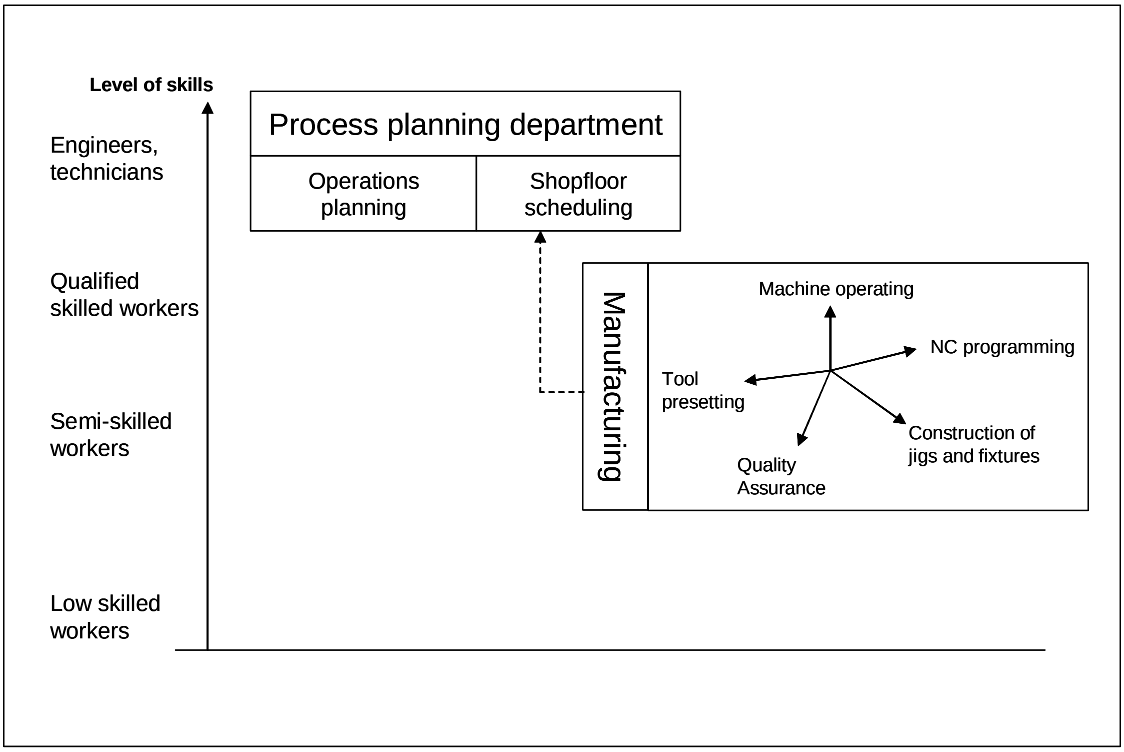

Figure 2.3 NC organisation: production islands (after Hirsch-Kreinsen, 1993)

Kelley (1990) goes much deeper into the subject of management choice. With new technologies come new skills. Hence, there is scope for role changes (Kelley, 1990). Organisational attributes are what make factories unique entities. Choice is therefore constrained by economic, organisational and institutional forces, such as the labour market and labour relations (Kelley, 1990); as is alluded to by Kidd (1988). Equally, choice is shaped by product markets (Kelley, 1990). Kelley observes that work structures offer decentralised control and broad job content where ‘customised products’ are manufactured. Hence, where small ‘organic’ structures are required, “blue collar” (i.e. shopfloor) programming is employed; whereas, in large “mechanistic bureaucracies” work is more specialised via divisions of labour. Thus, Kelley (1990) cites scale as a constraint on choice. Where organisational scale is greater, so is bureaucracy and therefore greater divisions of labour exist.

Nevertheless, Kelley’s work refers to US industry. Hirsch-Kreinsen (1990) reports contrasting influences on choice in the US and in Europe. In the US the general policy is to maximise the use of automation, because of a strong military influence on demand, the widespread rationalisation of labour and a general lack of skilled labour (Hirsch-Kreinsen, 1990). Whereas in Germany and other European states, the focus is on process rationalisation by using control systems that enable process flexibility, because European industry is more market-oriented (Hirsch-Kreinsen, 1990). Yet there are further national differences within Europe. Badham (1994) quotes these different national contexts of the same technology to be due to “unchanging socio-technical traditions”. Comparing British and German CNC manufacturing, Badham finds that British factories have more indirect functions which leads to fragmented organisations, whereas the Germans prefer to employ more technically-based managers throughout their hierarchies. Yet, despite having this rigid, specialist knowledge at a management level, German industry does favour a greater devolution of responsibility by employing shopfloor programming (Badham, 1994; Hirsch-Kreinsen, 1990). Hirsch-Kreinsen (1990) describes this system as “work-process orientation”, which aims to gain even greater flexibility than in the existing factory structures identified in figures 2.1

and 2.2. Although this has been pursued in many countries, it has been most widely accepted in Germany.

Hence, there are clear indicators of the choices available to management and the limitations of each. In their own review of the available literature, Pagell and Barber (2000) tabulate the influences upon the skill requirements in CNC machining (refer to table 2.1).

Influences upon a deskilled environment	**Influences upon a highly skilled environment**
Unionisation	Variability and uncertainty
Large scale production	High task complexity
Mature products	Good firm performance
A shortage of skilled labour	Growth stage products
Strategic focus is on cost reduction	Good labour relations
	Older workers (i.e. they are least likely to accept change)
	Strategic focus is on differentiation

Table 2.1 Influences upon the skill requirements in CNC machining (after Pagell and Barber, 2000)

Thus, considering the many influences on skill set choices, it is evident that the CNC machinist as described in section 2.1 exists in many forms. As discussed, depending on the constraints of a production system, a CNC machinist will be required to use a certain amount of skill and knowledge. By taking a broad perspective of the metal cutting industry, a scale could be produced. Bengtsson and Berggren (1989) offer just such a scale based on Swedish case study evidence, where organisational size defines the range machinist skills required in particular organisational contexts (see figure 2.4).

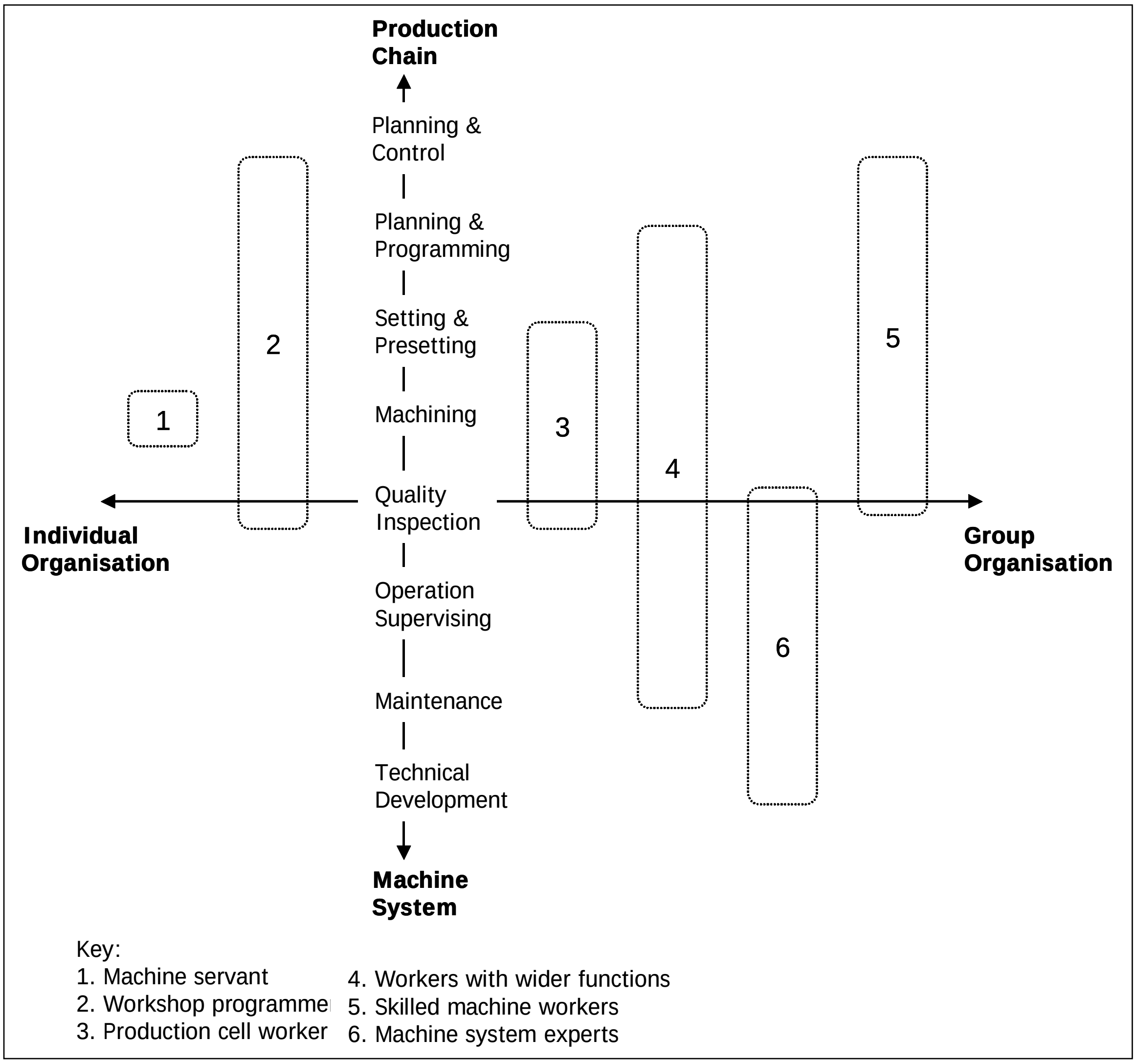

Figure 2.4 Six types of CNC machinist (after Bengtsson & Berggren, 1989)

But what of those machinists who undertook extensive apprenticeships to find that their full range of skills is not utilised? The findings of Dutch case studies show that this is not uncommon. CNC machinists are found to be over-skilled, have minimal involvement in their work and have lost the ability to influence product attributes (ten Have, 1989). With this in mind, a branch of industrial science has raised the question of what can be done to better utilise the workforce.

2.5 The skill-based paradigm

Bainbridge's classic paper (1983) seeks to highlight the paradox that all automated systems are in fact man-machine systems. Bainbridge identifies the irony that the more advanced a control system is, the more crucial the human contribution is! Hence, automated machines are intrinsically dependant upon human support (Bainbridge, 1983). Thus, where skills are neglected, surely process performance suffers?

The work organisation that Hirsch-Kreinsen (1990) defines as work-process orientation, and Bainbridge's ideas (1983) have been researched to understand skill utilisation. This body of work defines the *skill-based paradigm* (Hirsch-Kreinsen & Schultz-Wild, 1992; Kidd, 1994; Corbett, 1989; Jackson & Wall, 1991). A detailed examination of this literature is provided.

Hirsch-Kreinsen & Schultz-Wild (1992) state that skill-based work organisation represents a paradigm shift. Empirical data from Germany find that new factory structures are taking advantage of existing skill and qualifications, seeking to secure and increase the potential for innovation and adaptability. Economic change and market restructuring due to German reunification was a driver of this paradigm shift (Hirsch-Kreinsen & Schultz-Wild, 1992). However, skill-based manufacturing is observed elsewhere. Kidd (1994) also ascertains that the competitive pressures of changing world markets are the drivers for implementing skill-based work organisations. Organisational structures must become more responsive through better utilisation of human skills and experience, and modern computer-aided technologies. Kidd (1994) therefore claims the benefits of increased productivity, better quality and greater flexibility will be achieved to remain competitive. Equally, Wall, et al. (1990) find that there is a need to develop multi-skilled operators, cut across traditional skill demarcation lines, reduce functional specialisation, and develop flatter and more decentralised structures. Hirsch-Kreinsen & Schultz-Wild (1992) do, however, warn that whilst skill-based concepts are capable of guaranteeing long term economic efficiency, this form of work will not be widely employed due to the risks of changing existing organisational structures and the decreasing supply of skilled labour, as observed in Germany in 1992.

Nevertheless, at a more fundamental level, skill-based production is explored in more detail by Shultz-Wild (1993). Shultz-Wild finds that shopfloor programming has increased since the 1980s and there is scope for further increases. However, the research findings are not restricted to programming. Schultz-Wild states that strategic deployment of skilled labour enables shopfloor-based planning and control, tool preparation and management and maintenance and repair. Jackson & Wall (1991) take this argument further in their definition of a skill-based explanation of CNC machine tool downtime reduction. Machine tool faults are prevented by operators developing and using informal knowledge and skills. Experimental data shows that downtime is incrementally reduced over a period of time through learning and experience (Jackson & Wall, 1991).

The skill-based concept therefore involves more than merely devolving conventional office-based functions to the shopfloor. The work of Jackson and Wall suggests that by enabling CNC machinists to use their knowledge and experience, process performance improves. This assertion is supported by the qualitative data of Seppälä, et al. (1989), who state that as well as traditional metal cutting skills, CNC machinists in small batch, flexible production require independent decision-making and work planning skills for system manipulation and process sequence optimisation. The result is greater autonomy and freedom of movement than conventional machinists. Tuominen, et al. (1989) present a particular case where a CNC operator with extensive theoretical knowledge had the competence to master a broad job content. Utilisation of more knowledge than was conventionally required enabled more decision-making and control.

Mårtensson and Stahre (1992) state that operators must be in charge of advanced manufacturing systems, and therefore require proper competence development and suitable tools. Sauer, et al. (2000) extend this argument by introducing the concept of the CNC machinist performing a *compensatory function*. Acknowledging that German industry is committed to quality through the utilisation of highly qualified staff, Sauer, et al. present an empirical study of the role of CNC machine tool operators. The paper discusses the conventional boundaries within CNC manufacturing, stating the need for cooperation between programmers and machinists to rectify programming errors. Hence the CNC machinist compensates for inherent process deficiencies and therefore performs a compensatory function. However, the operator's role in this context is less than equal to that of the programmer. Sauer, et al. therefore recommend redesigning the role of the CNC operator. By assigning the operator a key role in the process, it is claimed that better cooperation across organisational boundaries would be possible. Sauer, et al. recommend that programmers and designers collaborate with operators to tap into their expert process knowledge with the aim of improving their own knowledge, thereby reducing pre-processing errors. It is, however, pointed out that any advantage gained from increased collaboration should not be offset by the increased time required. Hence, Sauer, et al. recommend improved efficiency of cross-boundary communication.

2.6 Skill enhancing technologies

The reviewed literature makes a case for skill-based organisations and describes the skills required for improved CNC manufacturing performance. However, the enablers of these new factory structures have not yet been discussed. Information technology is an enabler, and has the capability to influence people's job content (Kemp & Clegg, 1987).

Yet, the influence of information technology is not always positive. A UK-based case study found that flexible, multi-skilled CNC machinists, operating in a decentralised organisation were dissatisfied with the implementation of a shopfloor information system (Kemp & Clegg, 1987). This system was implemented to collect shopfloor data for production control. Kemp and Clegg report two issues identified by the data. Firstly, the machine tool operators were aware of problems within the manufacturing system, namely: poor integration and cooperation, too little and inaccurate information, and a lot of wasted time due to non-liaison between departments. The second point made is that management chose not to address these issues and instead implemented a shopfloor data collection system for increased production control. As a result, machinists saw this as an attempt to relocate operational control with management away from the shopfloor. Hence, management had a choice in this case, but chose the wrong solution. Kemp and Clegg (1987) find that the chosen system could change CNC operators' roles and overall job complexity could reduce. In recommending an improved solution, Kemp and Clegg believe that manufacturing systems synergy is possible via the design of human-centred information technology. Kemp and Clegg observe that some companies are enhancing skill via advanced technologies, recognising the critical human role in improving performance.

In support of this argument, Mikler, et al. (1999) present empirical data to show that a manufacturing system aiming for increased volume flexibility through multi-skilled operators leads to a demand for better information to shopfloor personnel. It is found that clear and appropriate information has many benefits: clear instructions and job descriptions, potential for work rotation, product variant information and increased feedback communication in the quality system (Mikler, et al., 1999).

From a more theoretical viewpoint, Kidd (1992) also discusses human-centred shopfloor information systems developed to enhance skill. Kidd (1992) finds that CNC operators must be involved in a process rather than merely intervening when the process stops, as discussed by Sauer, et al. (2000). Hence, management must view skill as a necessity rather than as a desirable feature. Appropriate information systems are therefore necessary to support skill. Referring to the work of Hazlehurst, et al. (1969), Kidd (1992) asks how information systems can support 3 of the 4 skill sets: perceptual, conceptual and discretionary skills. Hence Kidd (1992) poses the following questions:

- "Is it possible to develop a computer-based system that will support perceptual skills, and allow the machinist to identify potential problems before they occur?"

- “Can conceptual skills be supported such that they are applied in a way that allows the machinist to determine which cutting tools to use and what depths of cut, feeds and speeds to use?”

- “And can the computer be used to allow the machinist to exercise discretionary skills by choosing to change actions in the light of operating experience or results emerging from analysis?”

Kidd (1992) goes on to describe a computer-based system that is designed to address these questions. As a result, Kidd makes one final statement in which research into the development of new skills is considered necessary. Such new skills are cited as: innovation skills, team skills and communication skills. This mirrors the findings of research discussed previously. However, Kidd does not discuss any evidence to support this view, and only describes the conceptual design of the system. Hence, the author does not consider that the questions listed are fully answered. It is therefore necessary to review relevant information systems literature to understand whether sufficient information systems support of CNC machinist skills is possible.

2.7 Chapter summary

In gaining an understanding of the CNC machinist, the social, technological, economic and political dimensions have been addressed to find that the CNC machinists we see today have a complex history of technological and organisational change. The results are highly skilled operators that work within one of three environments: a highly automated factory with extensive divisions of labour, an automated factory with consideration of workers skill, and a decentralised, skill-based automated factory (Hirsch-Kreinsen, 1993; Kidd, 1988).

Where skill is not considered to be an essential factor, CNC machinists are generally devalued and under-utilised (Braverman, 1974; Linstrum, 1991; Kidd, 1988; Pagell and Barber, 2000; ten Have, 1989). However, where skill is valued, the benefits are substantial in terms of increased job content to improve production flexibility and product quality to better meet changing market demands (Hirsch-Kreinsen & Schultz-Wild, 1992; Kidd, 1994; Wall, et al., 1990; Jackson & Wall, 1991; Seppälä, et al., 1989; Tuominen, et al., 1989; Mårtensson and Stahre, 1992; Sauer, et al., 2000; Kemp & Clegg, 1987; Mikler, et al., 1999; Kidd, 1992).

Several recommendations are made both to take advantage of existing skills and to develop new competences. The recommendations of the skill-based research discussed can be classified as either:

- A requirement to increase the independent decision-making capabilities of the CNC machinists;
- Or a requirement to reduce demarcation between traditional functional boundaries.

Tables 2.2 and 2.3 summarise the key points from the literature to confirm these two classifications.

Recommendations to promote independent decision-making
Increase shopfloor programming and **strategic deployment of skilled labour** to enable shopfloor-based planning and control, tool preparation and management, and maintenance and repair (Shultz-Wild, 1993).
Make **use of informal knowledge and skills** (Jackson & Wall, 1991).
Promote **independent decision-making and work planning skills** for system manipulation and process sequence optimisation. The result is greater autonomy and freedom of movement (Seppälä, et al., 1989).
Utilise more knowledge than was conventionally required, enabling **more decision-making and control** (Tuominen, et al., 1989).
Provide competence development and suitable tools for **operators to be in charge of advanced manufacturing systems** (Mårtensson and Stahre, 1992).
Make information clear and appropriate to increase volume flexibility (Mikler, et al., 1999).
Support skills, including innovation skills, via appropriate information systems (Kidd, 1992).

Table 2.2 Recommendations relating to increased autonomy from the reviewed literature

Recommendations to enable cross-boundary communications and collaboration
Cut across traditional skill demarcation lines, reduce functional specialisation, and develop flatter and more decentralised structures (Wall, et al., 1990).
Improve the efficiency of cross-boundary communication by enabling programmers and designers to collaborate with operators to tap into their expert process knowledge with the aim of improving their own knowledge, thereby reducing pre-processing errors. (Sauer, et al., 2000).
Achieve manufacturing systems synergy through the design of human-centred information technology (Kemp & Clegg, 1987).
Provide clear and appropriate information, to increase volume flexibility (Mikler, et al., 1999).
Support skills, including team skills and communication skills, via appropriate information systems (Kidd, 1992).

Table 2.3 Recommendations relating to increased collaboration from the reviewed literature

One further formal recommendation is made that encapsulates each of the above. Jackson and Wall (1991) recommend that future research should consider two aspects of the changing role of CNC operators:

1. "Having established performance benefits are possible by changing the role of operators, consider explicitly what skills operators are learning which allow them to prevent problems from occurring."

2. "The major impediments to workers performing effectively are the barriers to their discretion imposed by management. Allowing operators to undertake tasks previously performed by engineers produces substantial performance benefits."

Hence, the literature suggests that information technology, as an enabler, could support CNC machinists' skill, *but* the hypothesised changes in job content have not been conclusively tested (Kemp & Clegg, 1987; Mikler, et al., 1999; Kidd, 1992). Chapter 3 explores the use of information technology in more detail before identifying a gap in the knowledge.

3 Shopfloor information systems

In the previous chapter, section 2.5 presents an argument for skill enhancing technologies. It is suggested that electronic information systems could enable CNC machinist skill enhancement by employing human-centred design principles. The study of human-centred systems is a body of work in itself, and therefore requires review.

3.1 Human-centred information systems

Bohnhoff, et al. (1992) find that the concept of human-centred systems can be applied to all aspects of manufacturing systems design. Human-centred systems are “categorised by the attempt to balance the advantages of a technical solution to a problem with the skills and competences of people” (Bohnhoff, et al., 1992). Such systems support skill-based, flexible processes. It is also noteworthy that the term ‘human-centred’ is found to be substitutable with ‘skill-based’ and ‘anthropocentric’, and is similar in definition to the ‘socio-technical systems’ concept (Bohnhoff, et al., 1992). Furthermore, Uden (1995) defines the key issue of designing human-centred systems to be finding the balance between technological components and human skills and abilities. User participation in system design is found to facilitate this. Uden also finds that the terms ‘human-centred’ and ‘anthropocentric’ overlap.

Also referring to the whole manufacturing system, Badham and Schallock (1991) add to the argument for human-centred systems by viewing the computer as a “craft tool” to facilitate skill-based production. Computer systems should be designed as a “useful tool” for human experts, not as a replacement for expertise (Badham and Schallock, 1991). Hence three design imperatives for human-centred systems are presented: the status and operations of the system must be transparent to the user; the system users must be the main source of judgement; and users must have the maximum degree of autonomy in their own work and in indirect support functions. Human-centred systems should therefore: accept and develop the current skill of the user; allow a degree of freedom for users to shape their own behaviour and objectives; and unite the planning, execution and monitoring functions (Badham and Schallock, 1991).

Narrowing the focus of the human-centred concept, Odasso, et al. (1996) identify communication (i.e. information accessibility and visibility) as a crucial issue to be addressed for future manufacturing competitiveness. Odasso, et al. associate this need with a “human-based” approach. Hence, information systems within a human-centred manufacturing system must also employ the design principles that Odasso, et al. discuss.

Yang and Lee (1996) view workers within a human-centred manufacturing system as knowledge workers who play a central role in guiding, managing and co-ordinating the system. These knowledge workers therefore require an effective tool for providing consistent information to inform their actions. Yang and Lee (1996) demonstrate this via an information system in which the user interface employs human-centred principles. Bálint (1995) also makes a case for the importance of the human-computer interface (HCI) in a human-centred production system. HCIs serve as the bridge between man and machine, where the machine functions are deterministic, whilst the human is non-deterministic. Hence, Bálint highlights the need for adaptive interfaces to meet changing requirements as dictated by the user.

Vicente (2000) investigates the support of worker adaptation by human-computer interfaces. However, coming from a socio-technical systems (STS) background, Vicente finds there to be a difference between STS and HCI. Within manufacturing, there is an increasing emphasis on open-ended intellectual tasks and discretionary decision-making. Hence, Vicente finds that HCI research is becoming evermore concerned with worker adaptation. That is to say workers are increasingly required to use their expertise and ingenuity to improvise novel solutions. Socio-technical systems are found to be open systems that cause workers to adapt to unfamiliar system disturbances (Vicente, 2000), designed for joint optimisation of the technical *and* social systems (Hyer, et al., 1999). Hence, with the aim of flexibility in mind, adaptive HCIs are better designed by considering socio-technical systems principles.

Hyer, et al. (1999) define nine principles that should govern STS design with respect to manufacturing cell design. Collectively, these principles confirm that STS aims to offer workers the ability to adapt to changing circumstances. Defining what is to be done is acceptable, but defining how it is done would inhibit worker creativity or adaptation. Potential users of such a system should therefore provide a design input (Hyer, et al., 1999).

3.2 Task support information systems

The term 'support' has featured throughout the reviewed literature in relation to the support of individuals in their tasks. Hence, literature related to information systems for task support is also reviewed.

Stahre (1995) refers to a 1987 study of Swedish FMS[12] operators that found operators to spend more than 50% of their time on outright manual tasks. Stahre therefore considers it crucial to identify operator tasks to provide adequate operator support.

Bullinger, et al. (1994) describe the shopfloor-oriented production support concept, which aims to provide work enrichment and work enlargement through information technology (IT) systems. This work's focus is on CNC programming, shopfloor control, quality assurance and resource management in decentralised work organisations to make effective use of human capital (Bullinger, et al., 1994). The reported research includes the development of an information system for shopfloor programming located at production islands. This system is designed to enable competence support, sequence of action flexibility and task appropriateness via an effective and efficient user interface (Bullinger, et al., 1994). The resultant system is therefore reported to support the knowledge and experience of users for shopfloor programming without placing constraints on them. Bullinger, et al., (1994) provide an illustration of

[12] FMS – flexible manufacturing system. Continuous machining is enabled by off-line tool and fixture changing.

the ideal system user (see figure 3.1). User participation in system development is considered necessary.

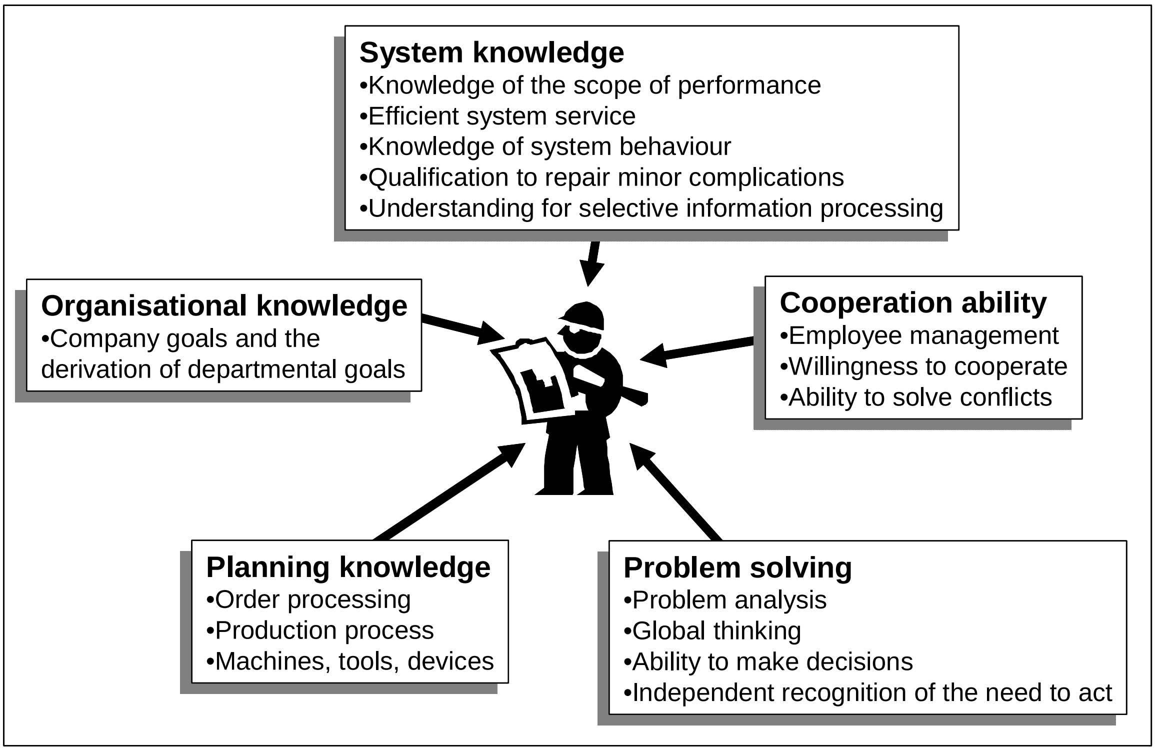

Figure 3.1 Ideal capabilities and knowledge of a task support system user (after Bullinger, et al., 1994)

Kasvi, et al. (1996) identify two developments that have increased shopfloor information requirements: the increased need for production flexibility, and the expansion of work content. In lightweight assembly production, experiential learning-by-doing is no longer viable with products changing often. Equally, the scope of an operator's work extends beyond the cognitive limits of the human mind. This is defined as competency overload (Kasvi, et al., 2000).

Although their work is aimed at lightweight assembly tasks, Kasvi, et al. (1996) report the development of an information system to provide all task-related information needed during assembly, and is therefore relevant to this research. The interactive task support system (ITSS) is used to study the possibilities and limitations of multimedia-based performance support at the shopfloor (Kasvi, et al., 1996). Such computer-based documentation can be used to either train inexperienced employees or to support experienced assembly workers.

With respect to designing ITSS for support, Kasvi, et al. (1996) discuss four sources of individual support: one's own memory, the social environment, the physical environment and the information environment. As well as relying upon memory, operators can get hints from their physical environment about correct work methods. They can also often depend on informal organisational networks for support. Hence, a performance support system should enhance such networks, as it can intensify existing communication lines and create new ones (Kasvi, et al., 1996). The information environment is also referred to, to access artefacts such as hand-written notes or work instructions (Kasvi, et al., 1996). Furthermore, Kasvi, et al. (2000) find three types of task requiring support by ITSS: the work task, the operation of the system itself, and problem-solving and creative tasks. Hence, a task support information system should be flexible, adaptive and expansive (Kasvi, et al., 2000).

3.3 Decision support systems

Another term used in chapter 2 is 'decision-making'. A substantial body of work defines and researches decision support. This literature is therefore also reviewed to clarify its contribution.

De, et al. (1985) define a conceptual decision support system to consist of three components: a language system (LS), a problem processing system (PPS) and a knowledge system (KS). A user interacts with the decision support system via the language system by inputting a problem statement, command or expression. The LS interprets this ready for processing by the PPS. The KS is then interrogated by the PPS for solutions. These solutions are then offered to the user after being processed and translated through the PPS and LS (after De, et al, 1985).

Of the literature previously reviewed, Kidd (1988) discusses decision support systems as a solution to support for operator skill. Kidd describes how a decision support system could be used by machinists in two ways. One way is for the computer to suggest cutting parameters, which the machinist can then edit. The second is where the machinist suggests cutting parameters, which the computer checks. Operator intervention could therefore be designed into the machining process to meet the aims of skill-based production.

Erbe (1998) also discusses decision support systems for CNC machinists. Via what is described as an information column, technical support for decentralised shopfloor decision-making could be provided. However, as with Kidd (1988; 1992), Erbe does not support this discussion with evidence. Indeed, De, et al. (1985) find "the ideal goal of a decision support system might be to automate the creation and transformation of logical data"; thereby automating blue collar and white collar functions. Although, this is not necessarily the intention of all decision support system developers, a focus on computer control rather than human control to increase the efficiency of decision-making is found by the author (Bhatt & Zaveri, 2002). Thus, decision support is rarely discussed using similar terms to skill-based literature.

3.4 Hypermedia systems

From the literature, shopfloor information systems to support operators' skill, knowledge and experience are required to provide work enrichment and work enlargement, and therefore need to be flexible, adaptive and expansive. In both of the task support studies discussed (Bullinger, et al., 1994; Kasvi, et al., 1996), hypermedia is employed to achieve this. Hypermedia is also considered in decision support literature (Hatcher, 1995). But what is hypermedia?

Hypermedia is defined as "an application which uses associative relationships among information contained within multiple media data for the purpose of facilitating access to, and manipulation of, the information encapsulated by the data" (Lowe & Hall, 1999). A simpler explanation is that hypertext is non-sequential (Nielsen, 1995). That is to say that conventional text has a single linear sequence defining the order in which it is read. Whereas hypertext does not prescribe the order in which the text is read, but provides references, or links, to related information. The individual reader therefore determines how to navigate the text (Nielsen, 1995). Thus in a computer-based hypertext system, multiple documents can be read in any chosen order and located via 'hyperlinks'. Hypermedia is an extension of hypertext, in that multiple media (i.e. multimedia) is cross-referenced via hyperlinks. The most common example of hypermedia is the worldwide web. Shneiderman (1989) finds that an application is suitable for hypermedia if it consists of:

- A large body of information which is organised into numerous fragments.
- The fragments are related to each other.
- The users need only a small fraction at any time.

Similarly, Lowe & Hall (1999) state the goals of hypermedia to be:

- To support (using the associative relationships between information sources) the carrying out of actions that result in the identification of appropriate information.
- To support the carrying out of actions which facilitate the effective use of information.
- To support the carrying out of actions that result in control of appropriate information.

Hypermedia can therefore manage the large amounts of information that CNC machinists require and effectively deliver only the specific information required at a given point in time.

The use of hypermedia in manufacturing is well reviewed. It is found that hypermedia has been under-utilised in manufacturing (Leung, et al., 1995 (part I)) and is largely driven by design engineering applications rather than shopfloor applications (Rahman, et al, 1999). However, hypermedia functionality can facilitate information integration, knowledge management, collaborative communication and team working (Leung, et al., 1995 (part II); Rahman, et al, 1999). Hence improved productivity and quality are achievable through improved information transfer and closer collaboration (Gunasekaran, et al., 1996).

In response to some of these points, hypermedia has become a proven collaborative tool. Other than the example of the worldwide web, Takahashi &

Yana (2000) present an example of hypermedia used for global collaboration, and find it to provide effective support. Equally, Esichaikul, et al. (1994) find hypertext to provide problem solving support for total quality management (TQM), as it permits access to information in a manner similar to human thought.

Schlick, et al. (1995) find that CNC machinists could benefit from the provision of multimedia documentation at the machine tool interface. One such feature would be pictorial representations of complex information. Hence hypermedia is recommended. It is found that in support of the information at the machine tool interface, CNC machinists require engineering drawings, manufacturing and tooling instructions, and details of the CNC program (Butcher & Greenough, 2000).[13] Where large amounts of procedural instructions and specifications are required, Hosni and Okraski (1992) also recommend hypermedia. The benefits are identified as:

- eliminating time-consuming searches for cross-referenced documents;
- providing a visual ‘memory jogger’ to supplement an operator’s knowledge of infrequently performed tasks;
- centralising operator information requirements.

The application of hypermedia in a large-scale industrial context does however come with a caveat. To benefit fully from the technology, a company’s culture must, and *will* change. The provision of information on a large scale will lead to democratisation of decision-making processes. Strong project leadership is essential to produce the shift in culture that is necessary to successfully implement industrial strength hypermedia (Crowder, et al., 2000).

Hypermedia is therefore reported to be able to deliver the multitude of information required in manufacturing and also enable collaborative support. It is clear that there is a case for evaluating a hypermedia-based information

[13] This is what is referred to by the sponsor as the technical package.

system to support CNC machinists, as required by the literature reviewed in chapter 2.

3.5 Information kiosks

Multimedia kiosks are PC-based workstations, specifically designed for public access (Rowley, 1995). They offer attractive and interesting means of presenting information in banking, advertising, retail education and training, by utilising the benefits of hypermedia-based (i.e. web-based) technology (Rowley, 1995). Hence, Rowley proposes that traditional boundaries within customer service sectors could be redefined.

Kiosks deliver multimedia via configurable browser interfaces and dedicated hardware to be usable, secure and robust. Kiosks in the public sector aim to continually attract new users to increase revenue; hence usability is essential. Equally, security is necessary to prevent misuse of the system. Robustness both reduces the cost of expert support and maximises availability for use. Slack and Rowley (2002) cite examples of kiosks being used in a wide range of applications to propose continued research. The application of kiosks in manufacturing could therefore be appropriate to add security and robustness to hypermedia-based systems.

3.6 Manufacturing instructions

Other than what has been reviewed, there is little evidence of research specifically aimed at manufacturing instructions for CNC machinists. Daude, et al. (1995) present an information system designed to provide manufacturing instructions to CNC machinists. Via a personal computer terminal, a CNC operator has access to the NC program, work plan, tooling sheet, part drawings, complete drawings and additional documentation. When using the system, the operator is able to comment on, edit or initiate feedback on the documents (Daude, et al., 1995). Hence the inclusion of an operator's experience creates a dynamic information system. This laboratory-based study does however focus only upon the man-machine interface, rather than consider the impact upon the machinist.

Another information system developed by Mikler, et al. (1999) comprises drawings, working and inspection instructions, tool descriptions and resetting information delivered via a shopfloor terminal. Mikler, et al. (1999) report a positive reaction from operators and considerable savings. Mikler, et al. (1999) also discuss an intention to develop the system to include dynamic behaviour. By enabling operators to input feedback, a learning system will evolve to offer greater knowledge and skill to operators. However, such developments have not been published.

Schlick, et al. (1995) also report the potential of hypermedia-based information systems for CNC operators. When discussing a survey of potential CNC machinists' requirements, the provision of multimedia documents such as photographic and moving images linked to a particular line in the machine tool program is identified. Such a system is predicted to better support the operator's knowledge (Schlick, et al., 1995).

3.6.1 Paper versus electronic documentation

Skill-based considerations are not the only issues when delivering manufacturing instructions via a computer-based information system. McLean (1990) finds serious and costly problems associated with the preparation, control and distribution of paper-based documentation. Time is wasted by workers locating the required instructions; and mistakes are made when the wrong revision of a document is used, or when the correct document cannot be found and the worker proceeds without it. As a consequence, both productivity and quality suffer (McLean, 1990). McLean therefore advocates hypertext-based documentation as a solution. A hypertext-based system is said to eliminate time wasted by operators searching for documents. It can also reduce mistakes by ensuring the correct revision is on the screen (McLean, 1990).

Survey data shows that 50% of manufacturing firms are unsatisfied with the current form in which information is available, and therefore the degree of information exploitation (Odasso, et al., 1996). It is also reported that 80% of technical documentation exists in conventional paper format (Lundeen, 2000). Considering a move towards digital documentation, Lundeen offers the use of scanning technology as a temporary solution for archived information. The move towards digital information systems in the defence industry is identified by Litman (1996). Of 105 major defence acquisition programmes, 65% required digital engineering drawings whilst 35% required digital technical manuals. Litman (1996) reports integration and collaboration on a large scale as some of the benefits of digital information.

Finally, Wills, et al. (2002) find that accurate retrieval of required information within a manufacturing system is considered time critical. Conventional information management techniques are found to be insufficient due to the vast amount of documents requiring cross-referencing in a variety of formats (Wills, et al., 2002). It is therefore stated that an estimated 10% of an organisation's technical assets (i.e. paper-based information) are either missing or incorrectly indexed. Wills, et al. (2002) also find that issuing updates to paper-based documentation is difficult to enforce rigorously. Crowder et al. (1999) provide an illustration of this situation and the contrasting solution via hypermedia (see figures 3.2 and 3.3).

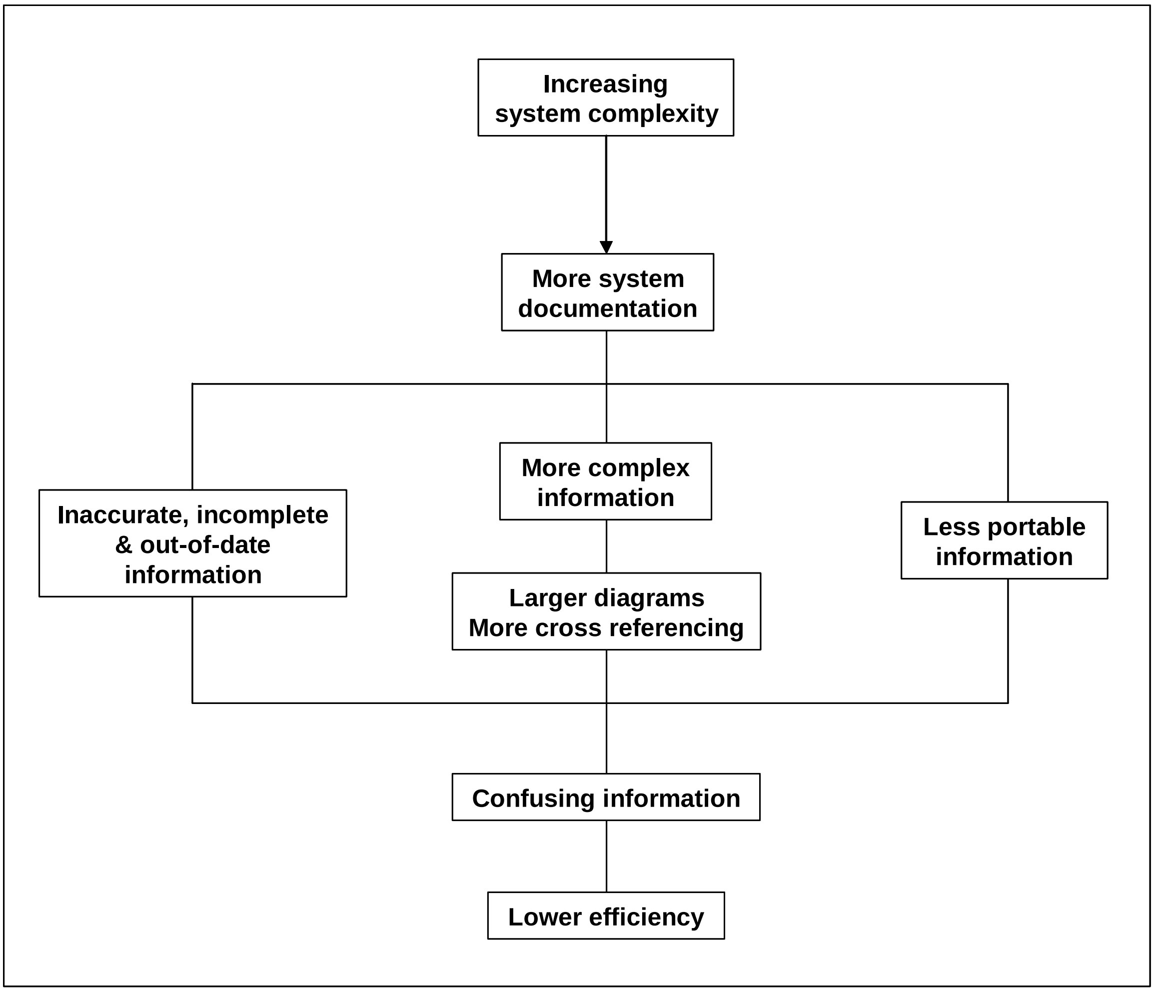

Figure 3.2 Summary of paper documentation problems (after Crowder, et al., 1999)

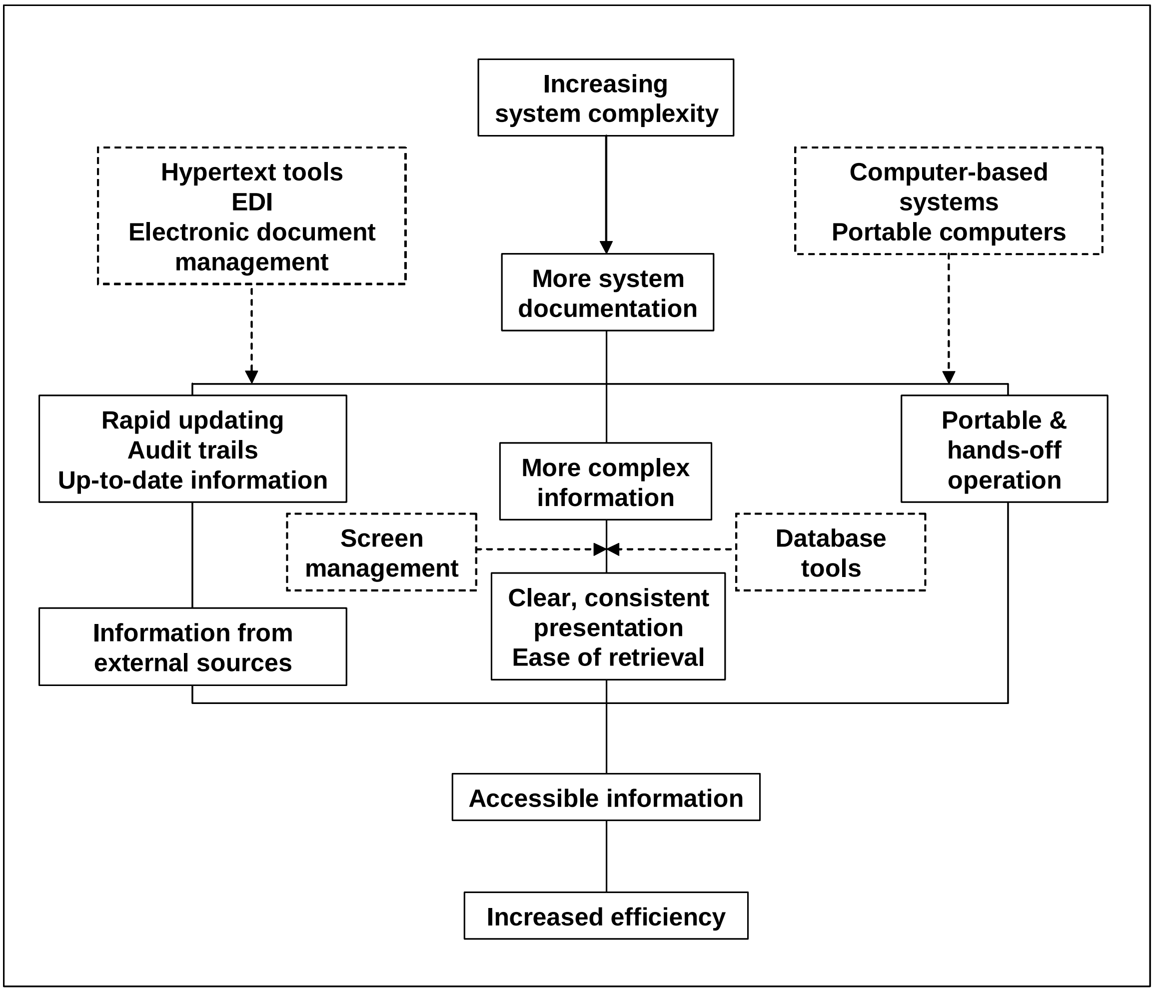

Figure 3.3 Summary of the benefits of open hypermedia for information management within manufacturing (after Crowder, et al., 1999)

It should however be noted that the introduction of hypermedia to manufacturing is to a large extent governed by its acceptance by shopfloor personnel (Crowder, et al., 1999).

3.7 Chapter summary

Several areas of research are drawn upon to produce a review of shopfloor information systems use. Human-centred design (Bohnhoff, et al., 1992) and task support (Bullinger, et al., 1994) are common features of such systems. Furthermore, manufacturing instructions-based information systems are discussed in the literature (Daude, et al., 1995; Mikler, et al., 1999; Schlick, et al., 1995). However, a gap in the knowledge is identified.

Chapter 2 focuses upon the role of CNC machinists and finds that an increase in the scope of their role could improve production flexibility and product quality. In particular, it is noted that increases in independent decision-making and cross-boundary communication are desirable to achieve the wider aims of the skill-based concept. To make this possible, sufficient information systems support is necessary.

Chapter 3 finds that various areas of information systems research have investigated the use of electronic information systems at the shopfloor, such as hypermedia. However, as yet, the impact of such systems upon the role of the users is not clearly defined in terms of support for independent decision-making and cross-boundary communication. It is therefore concluded from the review of relevant literature that it is necessary to research the impact of hypermedia systems upon CNC machinists' independent decision-making and cross-boundary communication capabilities.

Based upon this statement, research hypotheses are produced in chapter 4 to provide greater focus. A research methodology is then defined to modify and test the research hypotheses in line with the requirements of the research sponsor.

4 Research methodology

4.1 Research focus

As discussed in chapter 1, the sponsor requires an evaluation of existing and future shopfloor information systems support for CNC machinists. The literature reviewed in chapters 2 and 3 explores advances in CNC machinists' work organisation and in the delivery of manufacturing instructions. Hence, key issues for further research are identified and a research focus is defined. Nevertheless, a resource constraint was identified early in the project.

Integration of the information systems infrastructure is a Rolls-Royce strategic objective; whilst the literature review identifies hypermedia to be an appropriate technology for the presentation of manufacturing instructions. Hypermedia-based information systems were therefore central to facilitating this research. Nevertheless, preliminary investigation revealed that hypermedia-based manufacturing instructions are not currently used by CNC machinists within the company. Equally, Chapter 3 identifies few installations of shopfloor hypermedia systems at CNC machinists' workstations in UK manufacturing. The development of a prototype information system within Rolls-Royce was therefore required.

A suitable research methodology is now discussed to ensure that the research findings meet the research and business requirements, and to enable the development of a prototype information system.

4.2 Preliminary research hypotheses

Preliminary research hypotheses were defined to provide clear research objectives and therefore effective data collection and measurement (Rossi & Freeman, 1993; Robson, 1997).

From the literature reviewed in chapter 3, hypermedia was selected as the technology to be evaluated against existing Rolls-Royce information systems. To place sufficient boundaries on the research, the term '*hypermedia information systems*' was therefore used.

The literature reviewed in chapter 2 finds two prevalent factors that could impact the role of CNC machinists; namely ‘*support for independent decision-making*’ and ‘*support for cross-boundary communication*’. Hence the constructs for 2 distinct hypotheses were produced to define the following preliminary research hypotheses:

Preliminary hypothesis 1: **Hypermedia information systems for CNC machinists can support independent decision-making.**

Preliminary hypothesis 2: **Hypermedia information systems for CNC machinists can support cross-boundary communications.**

By testing these hypotheses, it was agreed with the research sponsor that the resultant knowledge of the impact of hypermedia information systems upon CNC machinists’ independent decision-making and cross-boundary communications would deliver an understanding whether such systems can increase the role of CNC machinists to benefit production performance. Hence, a significant contribution to the development of a business case for or against strategic implementation of such systems is provided by this research.

The selection and development of a research methodology to modify (Robson, 1997) and test these 2 hypotheses is now discussed.

4.3 Selection of a research methodology

The need to develop a prototype information system implied an experimental approach; thereby removing case study and survey approaches from further consideration as core research strategies. The experimental strategy was however also eliminated from consideration because maintenance of internal validity outside of a laboratory is found to be problematic (Robson, 1997). For an experiment to have internal validity, the cause of the experiment outcome must be attributable only to the variables tested (Robson, 1997). In an environment such as a metal cutting factory, the exclusion of non-measurable variables would clearly have been a problem. Hence the limitations of true experimental research in this context were exposed.

4.3.1 Evaluation

From the previous discussion, the word ‘evaluate’ was considered. Evaluation was found to be a distinct type of methodology (Robson, 1997; Patton, 1990; Rossi & Freeman, 1993). It is defined as “the systematic application of social research procedures for assessing the conceptualisation, design, implementation, and utility of social intervention programmes” (Rossi & Freeman, 1993). Robson supports this by stating the purpose of an evaluation to be “to assess the effects and effectiveness of something, typically some innovation or intervention: policy, practice or service.”

Robson goes on to state that an evaluation can employ experimental, survey or case study strategies. Nevertheless, evaluation has gained an increasingly high profile as a distinct methodology, because it emphasises the real world applicability of the research (Robson, 1997). Real world applicability is achieved by studying the social effects of policies and programmes and providing feedback on the effectiveness and efficiency of them to management decision-makers (Rossi & Freeman, 1993). Thus, considering the objectives of this research, an evaluation would study the social effects of the existing and prototype information systems, as required by the sponsor.

4.3.2 Formative and summative evaluation

Evaluation can be further categorised to separate the study of different research stages. Formative evaluation aims to assist the development of an intervention to a research setting by collecting detailed descriptive information about the existing environment and systems (Robson, 1997; Patton, 1990). An intervention or treatment is then applied to the research setting with the aim of improving it. Subsequently, summative evaluation assesses the effects and effectiveness of the intervention (Robson, 1997).

Applying a formative evaluation methodology to this research would facilitate the evaluation of existing shopfloor information systems. The addition of a summative evaluation would be appropriate to test the impact of the prototype information system.

Rossi and Freeman (1993) refer to impact assessment as a valid form of comparing groups in an evaluation. This is similar to the use of control groups in true experimentation. Whilst one group is subject to an intervention, a second group is not. It should however be noted that random allocation of the studied groups and the selection of a comparable 'isolated' control group are difficult to achieve in evaluations (Robson, 1997). Hence, assessing the impact of an intervention should be done with as much rigour as is practicable (Rossi & Freeman, 1993). For this reason, Robson (1997) emphasises the need for systematic information collection from a wide range of topics during an evaluation to capture unplanned and unanticipated outcomes to gain internal validity. Sufficient data should therefore be collected to measure the total result of an intervention, or "gross outcome" (Rossi & Freeman, 1993). Rossi and Freeman offer an algebraic explanation of this:

$$\text{Gross outcome} = \left\{ \begin{array}{c} \text{Effects of} \\ \text{intervention} \\ \text{(net outcome)} \end{array} \right\} + \left\{ \begin{array}{c} \text{Effects of} \\ \text{other} \\ \text{processes} \\ \text{(extraneous} \\ \text{confounding} \\ \text{factors)} \end{array} \right\} + \left\{ \begin{array}{c} \text{Design} \\ \text{effects} \end{array} \right\}$$

Thus to find the net outcome of an intervention, extraneous confounding factors and research design effects must be well documented to be isolated when assessing the net outcome (Rossi & Freeman, 1993).[14]

This discussion of the evaluation research methodology is interpreted in figure 4.1.

[14] Extraneous confounding factors will include human and environmental factors such as particular events during the research; whilst design effects will be artefacts of the research process such as errors of measurement and sampling variations (Rossi & Freeman, 1993).

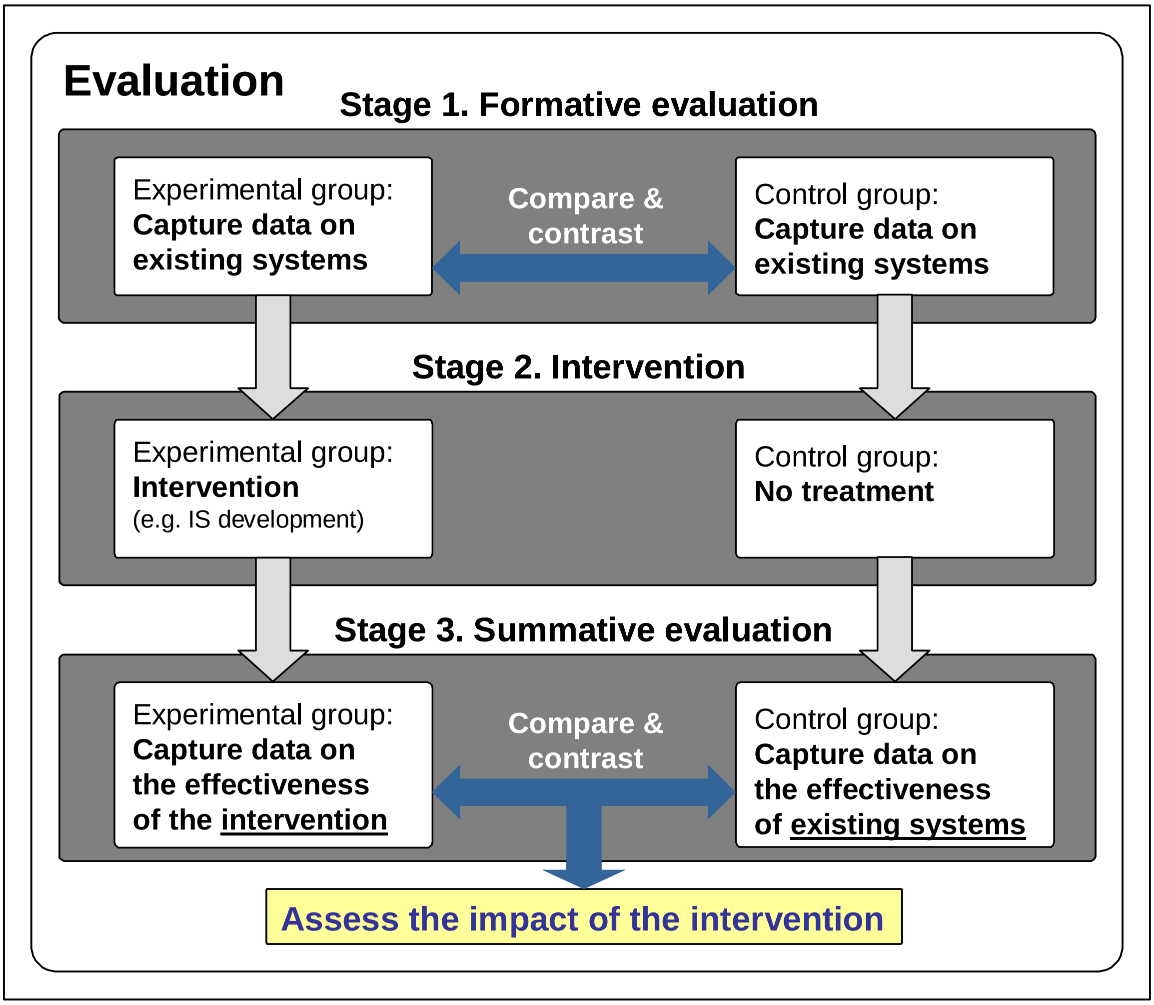

Figure 4.1 Interpretation of the evaluation research methodology

4.3.3 External validity

To achieve external validity, an impact assessment must be both reproducible and generalisable (Rossi & Freeman, 1993). Rossi and Freeman (1993) find that powerful evaluation research designs with numerous observational data will tend to produce similar results whoever conducts the research, thereby inferring reproducibility. However, generalisability is problematic in evaluations of trial or pilot systems due to their highly contextual nature (Rossi & Freeman, 1993). To overcome this, more than one evaluation would be necessary. Yet cost and time constraints commonly inhibit the employment of multiple evaluations (Rossi & Freeman, 1993). This was the case in this research. Hence, the adoption of evaluation alone could not separate the research findings from the context.

Where the boundaries between the phenomenon being researched and its context are unclear, Yin (2003) proposes using a case study strategy. By separately comparing the findings of each case against the theory, generalisable inferences are possible (Yin, 2003). It is therefore understood that minor case studies at other CNC machining environments would provide for inferences on the generalisability of the evaluation findings.

4.4 Modified research hypotheses

As discussed, an evaluation methodology requires the assessment of the 'effectiveness' of an intervention (Rossi & Freeman, 1993). By introducing this factor to the research hypotheses, greater clarity of the research outcome was provided for (Robson, 1997). The modified research hypotheses are expressed as:

Modified hypothesis 1: **Hypermedia information systems for CNC machinists can <u>effectively</u> support independent decision-making.**

Modified hypothesis 2: **Hypermedia information systems for CNC machinists can <u>effectively</u> support cross-boundary communications.**

4.5 Development of the adopted research methodology to test hypothesis 1

To test the 2 research hypotheses, the core research activity comprised the evaluation of existing and prototype information systems at a selected research setting within the sponsoring company. Two groups of CNC machinists were selected as participants; where one was the experimental group and the other was the control group. The experimental group was subjected to an intervention (i.e. prototype information system development) whilst the control group was not. Subsequently, case studies were required to generalise the evaluation findings. For clarity, the methodologies for each hypothesis are discussed separately.

4.5.1 Formative evaluation

The overall aim of the formative evaluation was to collect detailed descriptive information about the existing environment and systems (Robson, 1997; Patton, 1990). Systematic information gathering was therefore necessary (Robson, 1997). This was achieved via formal and informal observation and interviews of CNC machinists and other relevant stakeholders. These data were recorded via fieldnotes (Emerson, et al., 1995). A journal was also kept by the author to provide commentary on research activities and significant events.[15]

Independent decision-making tasks performed by CNC machinists were defined to produce requirements for the prototype information system. This was achieved via task analysis (Kirwan & Ainsworth, 1992). Richardson, et al. (1998) find that task analysis provides functional requirements as well as information requirements and is thus able to incorporate human factors into developed information systems. Quoting human-centred principles, Faulkner (2000) supports this by stating that system users' tasks must be understood to deliver an appropriate design that does not replace those tasks, but support them. Stahre (1995) also stresses the need to identify machinists' task to provide adequate support.

Faulkner (2000) goes on to discuss the construct of a task as a hierarchy of subtasks to fulfil a goal. Hierarchical task analysis (HTA) provides a structured diagrammatic approach to modelling the organisation of tasks within a system (Kirwan & Ainsworth, 1992). Faulkner (2000) prescribes interviews as an effective method of gathering information about a task. Sound and video recording, and talk-throughs are among the interview methods listed by Kirwan and Ainsworth (1992). The talk-through technique was favoured in this research, as it was found that by placing the interviewee in an expert role, they enthusiastically offered a detailed account of their tasks *and* their views.

[15] To sort and filter these data, a spreadsheet was constructed.

The task analysis was transcribed and modelled in $IDEF_0$ format (Wu, 1994). It was found that presenting such a detailed system of tasks and subtasks is difficult if restricted to the relatively simple hierarchical task analysis models demonstrated by Kirwan and Ainsworth (1992). Comparing the two modelling methods, the $IDEF_0$ approach is better able to structure many task hierarchies over several sheets of paper, thereby enabling more efficient visualisation of the system than HTA. However, it was also found that the basic $IDEF_0$ model could not sufficiently model a complex series of decisions required in certain sub-tasks. The conversion of decision-making sub-tasks to a flow chart format provided a more familiar format for the author to refer to. A list of independent decision-making tasks was therefore extracted from the model and verified with the research participants.

Finally, by recording observed task durations as part of the task analysis, a comparison with the prototype system results would later be possible (refer to section 4.4.3). Converting these mean durations to 'standard times' (Aft, 2000) provided valid quantifiable data.[16] Aft offers the following equation: [17]

$$\text{Standard time} = (\text{Observed time})(\text{Rating factor})(1 + \text{PFD allowance})$$

4.5.2 Intervention

The development of a prototype information system was necessary to test the research hypotheses.[18] One objective of the system was to improve on existing paper-based information support for CNC machinists' independent decisions. The system was therefore developed to deliver information necessary to

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[16] Conventional work study was not possible due to industrial relations issues.

[17] The rating factor is a judgement of the pace at which an individual is working, expressed as a percentage of what is adjudged to be a normal pace. The PFD allowance is a percentage allowance for personal, fatigue and delay factors that may have influenced the individual studied. For the purposes of this research, the rating factor = 90%; whilst PFD allowance = 15%.

[18] Development of the prototype information system is discussed in appendix B.

support the independent decision-making tasks defined in the formative evaluation.

The intervention was facilitated by implementing the prototype information system at the workstation of the experimental group. The control group continued to use the existing paper-based information.

4.5.3 Summative evaluation

An impact assessment was employed to evaluate the effects and effectiveness of the prototype information system (Robson, 1997; Rossi & Freeman, 1993). Comparisons between the experimental group and the control group enabled analysis of what occurred as a result of the intervention and what occurred without it (Rossi & Freeman, 1993).

Effectiveness is a measure of how well a system achieves its intended results (Love, 1991). Love states that measuring the change of status of a system is suitable method for measuring effectiveness. The variables of which are found to be:

- Binary status (i.e. was a task supported or not?);
- Frequency (i.e. how often was that task supported?);
- Duration (i.e. how long was the task supported?);
- Magnitude or intensity (i.e. how great was the outcome?) (Love, 1991).

Hence, frequency and duration data[19] were collected from the experimental group for the defined independent decision-making tasks. Manufacturing engineering[20] provided approximations of frequencies and mean task durations,

[19] Frequency and duration are functions of binary status; hence binary status is inferred from frequency and duration data.

[20] Manufacturing engineering comprises CNC programmers and planners who produce the manufacturing methods.

based upon averages of each component produced by the control group, for comparison.[21]

An assessment of magnitude was obtained by comparing the mean durations[22] for each independent decision-making task during the summative evaluation period with the standard times collected during the formative evaluation. Hence, a measure of efficiency was attained. Karger and Bayha (1966) express this as:[23]

$$\text{Operator efficiency} = \frac{\text{Allowed standard}}{\text{Actual operator(s) time}} \times 100\%$$

Direct observation was not possible for the collection of these data, due to time constraints.[24] However, the prototype (i.e. kiosk) generates log file data, which show all web pages viewed. By analysing the content of these data during the summative evaluation period, frequencies and durations of individual information types (e.g. engineering drawing) were found. Further analyses converted these data to frequencies and durations of support for individual independent decision-making tasks.

To evaluate the gross outcome of the intervention, systematic qualitative information gathering continued (Rossi & Freeman, 1993). Observation and informal interview data were recorded via fieldnotes and journal records.

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[21] The high frequency of some tasks would have placed an unacceptable burden upon the control group if frequency data was required to be tallied. Supportable approximations were agreed to be an acceptable compromise.

[22] For the experimental group data, mean duration = total duration/frequency.

[23] Where allowed standard = standard time.

[24] Such a study would require observation 24 hours a day.

4.5.4 Case studies

Semi-structured interviews (Drever, 1995) and talk-through interviews (Kirwan & Ainsworth, 1992) were conducted with relevant stakeholders at 3 alternative research settings. One objective of these interviews was to capture qualitative data on information systems support for CNC machinist independent decision-making to validate the list of independent decision-making tasks.

The research methodology to test hypothesis 1 is illustrated in figure 4.2.

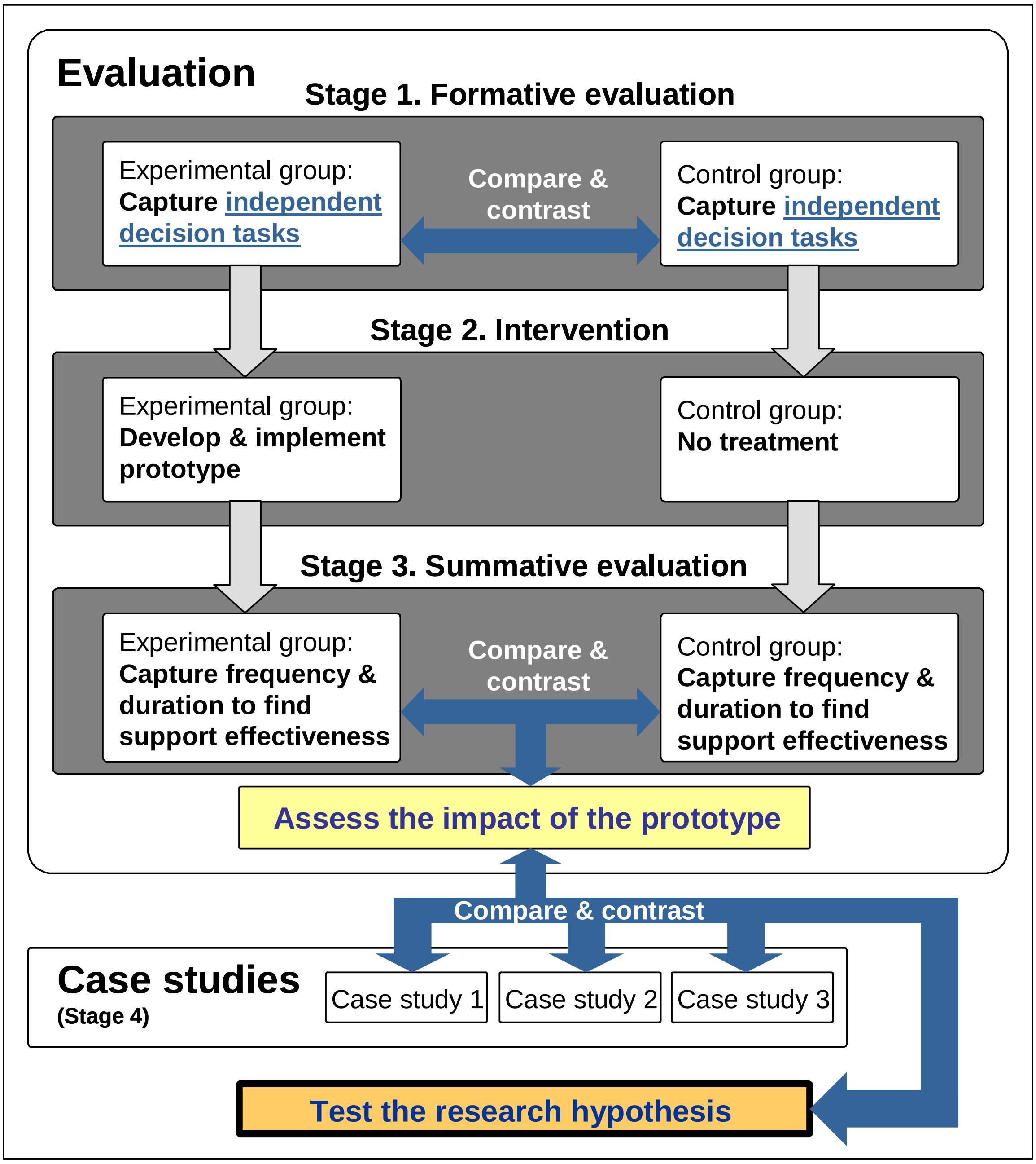

Figure 4.2 Research methodology to test hypothesis 1

4.6 Development of the adopted research methodology to test hypothesis 2

4.6.1 Formative evaluation

As discussed in section 4.5.1, systematic information gathering was achieved via fieldnotes and journal records to describe the existing environment and systems in detail.

To evaluate existing CNC machinist cross-boundary communications, a stakeholder analysis was conducted (Freeman, 1984; Johnson & Scholes, 1999; untitled, 1993). Stakeholders are those people who influence, or are influenced by the outcome of an evaluation (Rossi & Freeman, 1993). Hence, by collecting data on CNC machinist interactions with other people at the research setting, a list of stakeholders was produced. These stakeholders were classified by their influence upon the process. Estimates of the frequency of communication with each stakeholder were also provided to produce a quantifiable definition of existing CNC machinist communication boundaries.

4.6.2 Intervention

To test hypothesis 2, the second objective of the prototype information system was to support cross-boundary communications. The existing paper-based information system does not support cross-boundary communication. Face-to-face discussion was the only form of communication available to CNC machinists without the prototype. Hence, a hypermedia-based communication tool was developed to support the cross-boundary communications defined in the formative evaluation.[25]

The intervention was facilitated by implementing the prototype information system at the workstation of the experimental group. The control group

[25] Refer to appendix B for a discussion of prototype development.

continued to communicate without the support of the prototype information system.

4.6.3 Summative evaluation

As discussed in section 4.5.3, an impact assessment was employed to evaluate the effects and effectiveness of the prototype system (Robson, 1997; Rossi & Freeman, 1993). Comparisons between the experimental group and the control group enabled analysis of what occurred as a result of the intervention and what occurred without it (Rossi & Freeman, 1993).

To evaluate the effectiveness of CNC machinist cross-boundary communication support by the prototype information system, the change in communications status was measured (Love, 1991). Thus, by collecting frequency and duration data for each communication with another stakeholder, an evaluation of the prototype information system's support of cross-boundary communication effectiveness was possible. Hence, boundaries were redefined for comparison with the control group.

As previously discussed, direct observation was not possible for data collection, due to time constraints.[26] Qualitative research diaries (Symon, 1998) were therefore employed to collect cross-boundary communication data. Robson (1997) finds that diaries can act as a proxy for observation where it would be difficult or impossible to carry out direct observation. To minimise the burden on research participants, Robson (1997) recommends structuring research diaries as much as possible by asking a specific set of questions about a respondent's activities at set times. The diaries were designed accordingly, for the participants to collate descriptive data on occurrences of communications.[27]

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[26] Such a study would require observation 24 hours a day.

[27] Refer to appendix C.

To evaluate the gross outcome of the intervention, systematic qualitative information gathering continued (Rossi & Freeman, 1993). Observation and informal interview data were recorded via fieldnotes and journal records.

4.6.4 Case studies

As discussed in section 4.5.4, semi-structured interviews (Drever, 1995) and talk-through interviews (Kirwan & Ainsworth, 1992) were conducted with relevant stakeholders at 3 alternative research settings. The second objective of these interviews was to capture qualitative data on information systems support for CNC machinist cross-boundary communications to validate the boundaries defined in the evaluation research setting.

The research methodology to test hypothesis 2 is illustrated in figure 4.3.

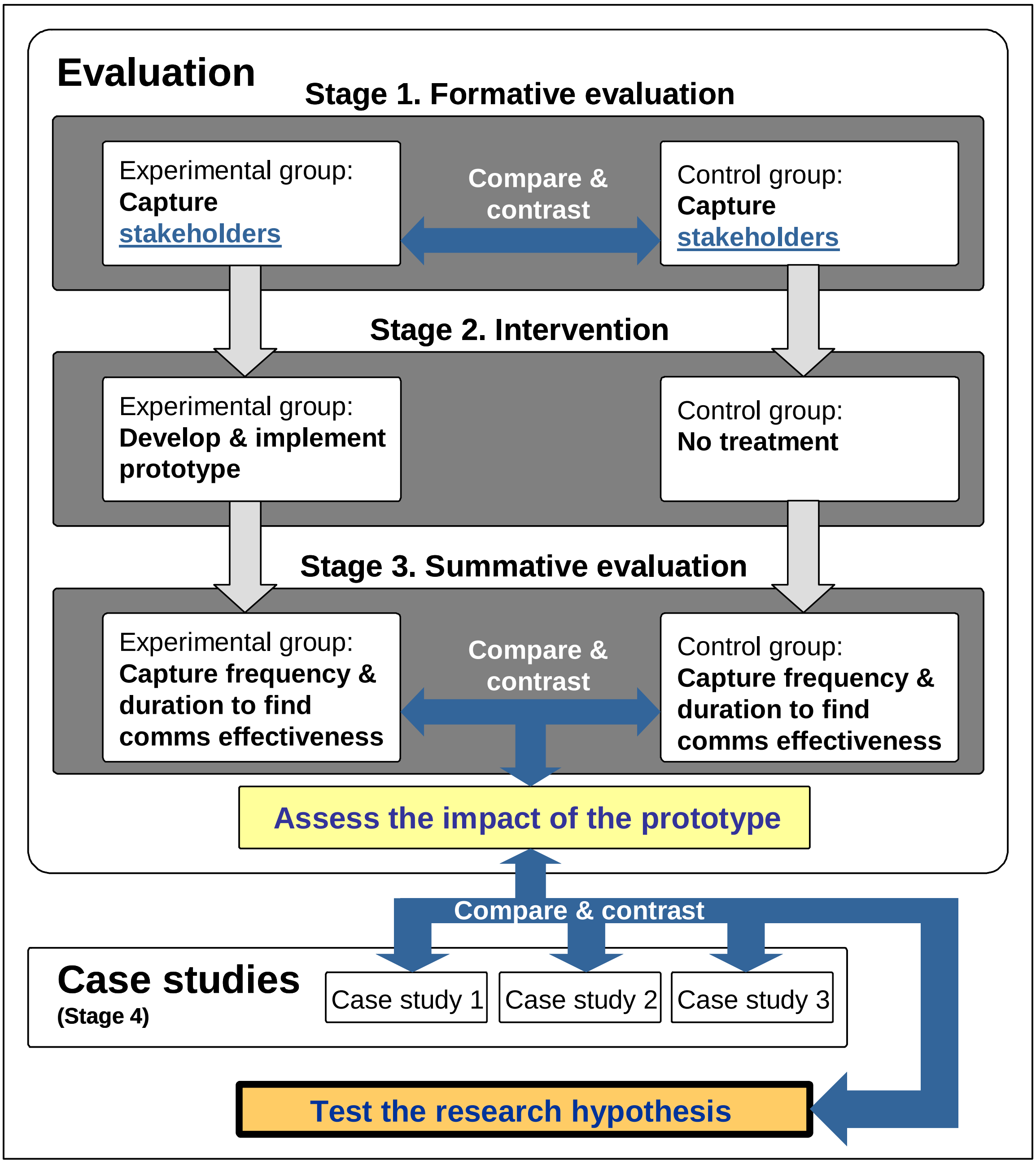

Figure 4.3 Research methodology to test hypothesis 2

4.7 Chapter summary

This chapter establishes the research focus and hypotheses. To test the two research hypotheses within the sponsoring organisation an evaluation methodology was adopted. Formative evaluation of the existing paper-based information system produced requirements for improvement. A prototype information system was then developed for summative evaluation. An experimental group used the prototype information system, whilst a control group continued to use the existing paper-based system. Comparison of data from the 2 groups provides an assessment of the impact of the prototype system with respect to the research hypotheses.

Nevertheless, generalisability of evaluation research findings is found to be difficult to achieve, due to time and cost constraints (Rossi & Freeman, 1993). Supplementary case studies were therefore employed to validate the findings of the impact assessment.

For clarity, the research methodology to test each hypothesis has been discussed separately. Chapters 5 and 6 maintain this format in discussing the research results.

5 Evaluation results

5.1 Definition of the research setting

5.1.1 Selection of CNC machinists for evaluation

The experimental group and the control group were selected from the same department within Rolls-Royce. The groups operate two CNC machining centres of similar specification, which manufacture the same components. Hence, each group operates in the same environment and are thus subject to the same extraneous confounding factors (Rossi & Freeman, 1993).

The total number of participants was 7 skilled CNC machinists. The department operates 3 shifts per day at each machine tool; hence there is 1 operator per machine per shift; plus 1 additional operator who provides cover for the department. Of the seven operators, 6 rotate between the two machine tools, whilst 1 operator works only at one of the machines.[28] This is best explained graphically (see figure 5.1).

It was therefore decided that the intervention was to be conducted at machine 1, with operators 1 to 6 forming the experimental group. Operator 7 was the control operator as he is the only operator not to work at machine 1.[29] It is understood that operator 7 could not be completely isolated from the experimental group, but in order to provide for comparable data the proximity of the two groups was a necessary compromise.

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[28] This operator is <u>not</u> the additional cover operator.

[29] Participants shall remain anonymous.

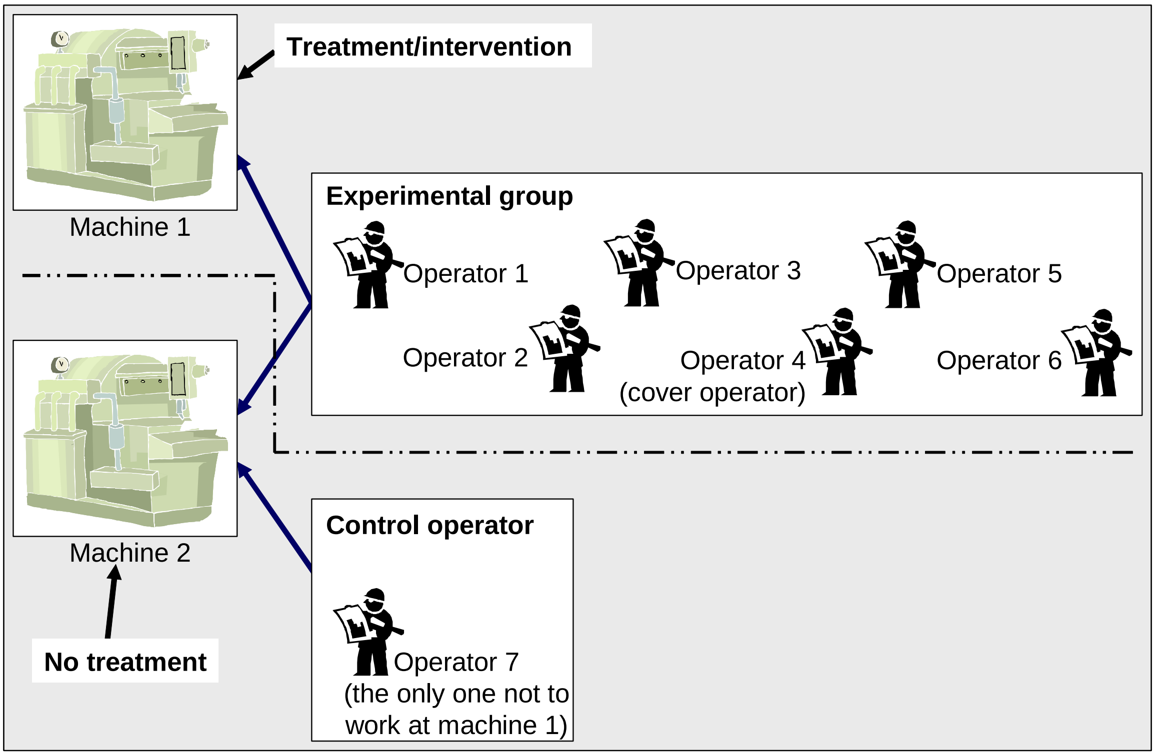

Figure 5.1 The experimental group and control operator for evaluation

5.1.2 Definition of the research setting

The 2 CNC machine tools operated by the research participants are 5 axis machining centres with interchangeable machine beds and automatic tool selection via a tool carousel. The components manufactured at these machines are large diameter combustion casings for defence aerospace turbine engines.[30] Four types of casing components are manufactured to various specifications. Cycle times for these components average approximately 40 hours. The rest of the department consists of various machine tools and treatment processes that perform other operations on the same components. Operationally, the department experiences low variation in demand, low product variety and moderate production volumes. Hence, operational objectives include the maintenance of consistently high levels of quality and productivity.

[30] These components are typically greater than approximately 2 metres in diameter and require the machining of radial surfaces and complex features.

The machine shop is managed locally by a 'cell leader' who is accountable for the department's shopfloor. The shop is then split into designated sections, each with 'coaches' (i.e. supervisors or foremen). The adherence of the production schedule is maintained by the coaches and a material controller. The process methods are produced by Manufacturing Engineering (ME), which consists of process planners and CNC programmers. ME produce the technical package (i.e. the information system that is the subject of this research), and is located in the same building as production.

5.2 To test hypothesis 1

From chapter 4, hypothesis 1 is defined as:

Hypermedia information systems for CNC machinists can effectively support independent decision-making.

5.2.1 Formative evaluation

A preliminary understanding of the creation and delivery of existing paper-based technical package was gained from interviews with stakeholders (refer to figure 5.2).

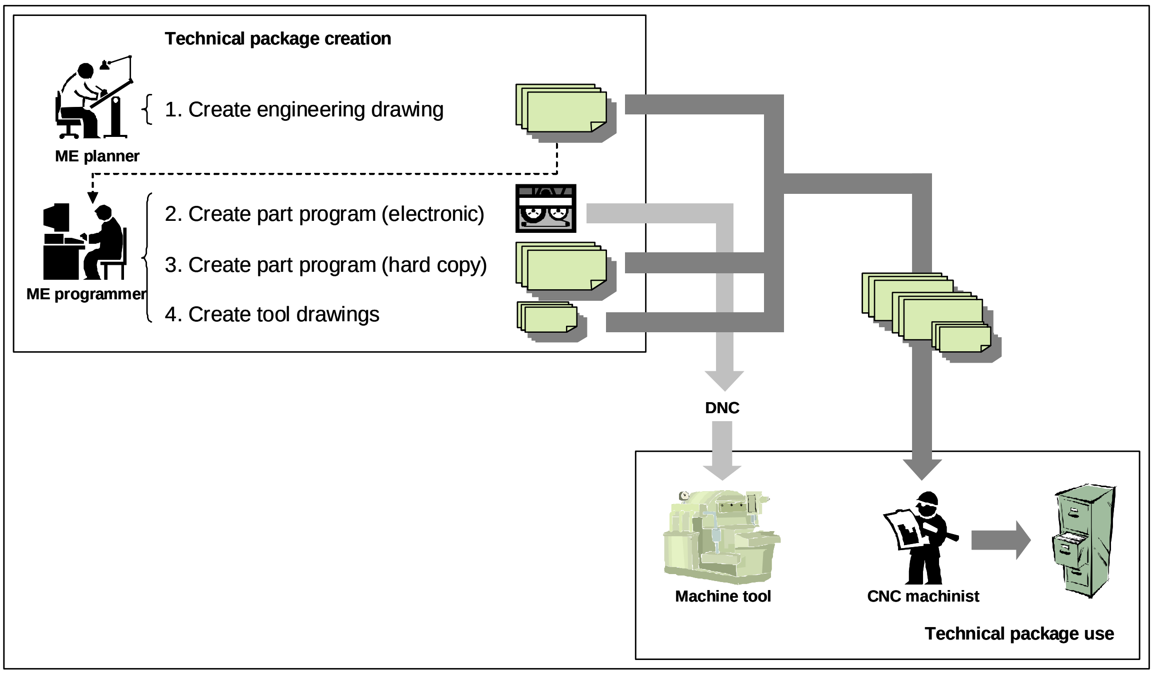

Figure 5.2 Technical package creation and delivery

Each operation for a particular component has 1 technical package. This consists of relevant engineering drawings, a paper-copy of the program and a set of tool drawings.[31]

Task analysis interviews provided preliminary evaluation of the use of the existing paper-based technical package. Usage by both the experimental group and control operator was found to be equal.[32] Yet, CNC machinists identified problems with the storage, presentation and use of the existing paper-based technical package (refer table 5.1).

Type of problem	Problem identified
Storage	Separate technical packages are not filed in any particular order. Machinists aim to keep a 'package' together, but differences in size, binding and finishing are limitations. The open-ended plastic cover for the part program provides an improvised wallet for the complete technical package, but this is not standard procedure; The result is time wasted checking whether all information is present and correct before use; implying a quality assurance issue.
Presentation	Where multiple drawing sheets exist for the same part number, they are not always kept in the correct order, due to a lack of binding. Non-laminated sheets are frequently smudged by dirty hands or coffee strains.
Use	Due to low process variability and storage problems, machinists refer to memory rather than the paper sheets to perform highly repetitive tasks. This overcomes time wasted sorting documents.[33] Documents are not always stored after completing an operation.

Table 5.1 Problems associated with the existing paper-based technical package

[31] Another document referred to by operators is the job card. A job card identifies the operations required to produce a component, and therefore stays with the job throughout manufacture. It is however, not considered part of the technical package in this environment.

[32] Illustrations of how the CNC machinists arranged the paper-based technical package at their workstations are also provided for reference in appendix A.

[33] This is not necessarily a problem, but demonstrates the system's reliance upon the machinists' knowledge to maintain productivity.

To achieve the primary objective of the formative evaluation, task analysis interview transcripts were analysed to produce a model of the work tasks performed by CNC machinists (refer to appendix A). Following verification of the model by the experimental group and control operator, a definitive list of 7 independent decision-making tasks supported by the existing paper-based technical package was defined (refer to table 5.2).

Independent decision-making task	Description	Observed duration estimates
Datum setting	Once the machinist has loaded the component on the machine tool bed, coordinate datums must be set. The machinist uses the **printed part program** for reference when typing pre-determined datum co-ordinates into the electronic program via the machine tool interface.	10 minutes
Checking gauge availability[34]	If this task is performed, the machinist will typically go through the relevant gauge bin referring to the **engineering drawings** to check that all required plug gauges are present and correct. Experience has shown that the system in place has been known to fail, causing machine idle time.	5 minutes
Checking tool availability[35]	If this task is performed, the machinist will go through the tool drawers at the workstation, checking that all required tools are available in sufficient numbers, whilst checking them against the **tool drawings**. It is more common for machinists to frequently monitor the tool stocks as part of their general housekeeping.	20 minutes
Checking which line the program is at	This information task appears to be simple but is effective. The machinist uses the **printed part program** to cross reference the program line number shown on the screen. Hence, *this task is central to the organisation of all other tasks*; in that the machinist will plan what to do next, based on what the current cut is.	0.5 minutes

[34] A formal system is in place for the storage and re-stocking of gauges. The machinists therefore generally tend to accept that all are present and correct prior to commencing a new job. This is therefore a rare task, but one which was discussed, and therefore included.

[35] Consignment stocking of tools means that tool reps restock the tool drawers on a weekly basis. Hence, machinists do not necessarily need to conduct this task during set up. However, it was also discussed as a possibility.

Inspecting machined dimensions and selecting the appropriate gauge	When necessary, the machine tool is stopped to inspect the dimensions produced by the previous cut. This can be pre-programmed or a knowledge-based decision made by the machinist. The machinist will read the tolerances for the dimension(s) in question from the **engineering drawing**. The appropriate gauge is then selected and the dimension measured.	10 minutes
Selecting replacement tools when worn or damaged	As the program selects a tool from the carousel, the machinist stops the program and inspects the tip tool for wear or damage. If worn or damaged, or if the tool is expected to perform multiple cuts, the machinist will elect to replace it. This is done by removing the tool holder from the machine and placing it in a 'pot' (i.e. fixture) at the bench. The tip tool is unfastened from the tool holder. The **tool drawing** is then referred to for the reference number and the corresponding replacement tool is selected from the tool drawer.	1 minute
Setting tool offset/ standout[36]	With the correct tip tool selected, it is located in the holder. To prevent re-calibration of the program, the tool tip must be positioned a set distance from the tool holder. This dimension is provided by the **tool drawing**. Once fastened in the holder, it is relocated in the machine tool ready to begin the next cut.	2 minutes

Table 5.2 Independent decision-making tasks

Table 5.3 provides the standard times calculated from the estimates for each independent decision-making task, as required for future analyses.

[36] Although this is a continuation of the previous task, it requires the machinist to refer to the tooling drawing again for different information. Hence for the purposes of this research, 2 distinct tasks are listed.

independent decision task	standard time observed
	duration (mins)
datum setting	10.4
checking gauges	5.2
checking cutting tools	20.7
checking program line	0.5
inspecting dimensions	10.4
selecting cutting tools	1.0
setting tool offset/standout	2.1

Table 5.3 Independent decision-making task standard times

5.2.2 Intervention

To provide for the testing of hypothesis 1, a prototype hypermedia system was developed to deliver information necessary to support the 7 independent decision-making tasks defined in table 5.2.[37] This was achieved by presenting the 3 core documents of the existing technical package (i.e. engineering drawings, a copy of the program and tool drawings) via the kiosk user interface.

Effective and efficient navigation of the system by the experimental group was confirmed by usability assessment. Figure 5.3 shows the interface for the kiosk-based technical package.

[37] Appendix B provides a discussion of the development of the prototype hypermedia system.

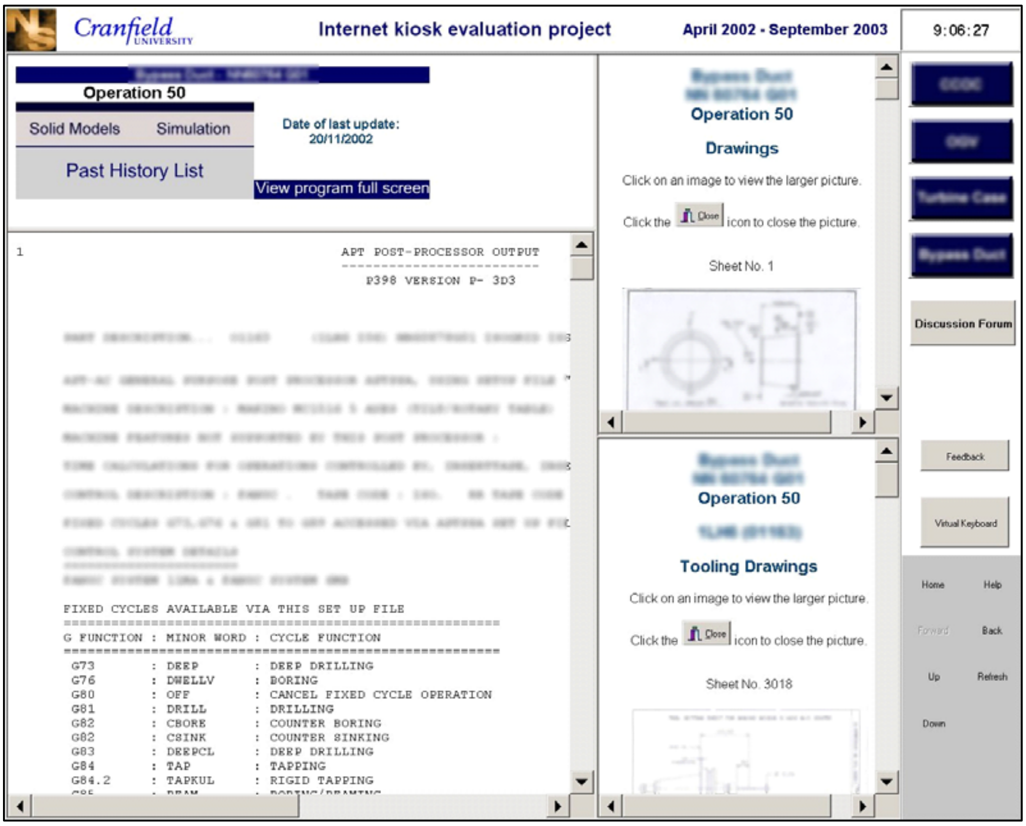

Figure 5.3 The kiosk-based technical package

5.2.3 Summative evaluation

To test hypothesis 1, evaluation of the effectiveness of kiosk support for CNC machinist independent decision-making is discussed. This was achieved by measuring the frequency and duration of kiosk use by the experimental group to support the 7 independent decision-making tasks defined in table 5.2. The experimental group data is compared with mean duration approximations of the control operator's use of the paper-based technical package[38] to evaluate relative effectiveness.

[38] Approximations were provided by manufacturing engineering, based upon the average number of occurrences for each component manufactured. High variability of task frequencies and durations, combined with an inability to measure the control operator, led to this compromise.

Results show that the frequency of kiosk use was low. However, the experimental group were able to refer to the existing paper-based technical package during the 3 month summative evaluation period, if necessary. A departmental requirement of quality assurance dictated that sole reliance upon the kiosk-based technical package was not possible. Hence, total duration was also low. This unavoidable constraint greatly influenced this research and is therefore discussed further in chapter 7.

From a total of 1536 hours that the kiosk was available for use, kiosk log file data shows that it was actually used for just 70 hours to support independent decision-making (refer to table 5.4).

	effectiveness					**efficiency**	
independent decision task	**Standard time from formative evaluation**	**Experimental group kiosk usage measured**			**Control group paper usage approximation**	**Experimental group**	**Control group**
	mean duration (mins)	*frequency*	*total duration (hours)*	*mean duration (mins)*	*duration (mins)*	*percentage*	*percentage*
datum setting	10.4	5	1.2	14.5	12.0	71.4%	86.3%
checking gauges	5.2	10	5.7	34.1	2.0	15.2%	258.8%
checking cutting tools	20.7	14	5.7	24.3	20.0	85.1%	103.5%
checking program line	0.5	24	3.9	9.8	0.5	5.3%	103.5%
inspecting dimensions	10.4	147	44.5	18.2	12.0	56.9%	86.3%
selecting cutting tools	1.0	53	4.7	5.3	1.0	19.5%	103.5%
setting tool offset/standout	2.1	14	4.6	19.7	2.0	10.5%	103.5%
			70.3				

Table 5.4 Effectiveness and efficiency of kiosk use to support independent decision-making

The experimental group results in table 5.4 are derived from comparing the log file data with analyses of information usage scenarios observed during task analyses and kiosk development.[39] These scenarios are defined in table 5.5.

[39] Kiosk log file data provided the frequency and duration that each web page was viewed. Whilst, through understanding how the kiosk was used to support each defined task, scenarios were created. Hence, by matching the scenarios with the raw log file data, individual occurrences of task support were identified via a structured approach.

Independent decision-making task	Associated information usage scenario			
	Information used	**Duration referred to**	**Whether it was left on-screen**	**What it was cross-referenced with**
Datum setting	Program	>1 min	Left on-screen but no longer used	None
Checking gauge availability	Engineering drawing	>20 mins[40]	Continuous reference	None
Checking tool availability	Tool drawing	>20 mins	Continuous reference	None
Checking which line the program is at	Program	< 1 min	Left on-screen but no longer used OR Not left on-screen	None OR engineering drawing
Inspecting machined dimensions and selecting the appropriate gauge	Engineering drawing	<20 mins	Left on-screen but no longer used OR Not left on-screen	None
Selecting replacement tools when worn or damaged	Tool drawing	<20 mins	Not left on-screen	Engineering drawing
Setting tool offset/ standout	Tool drawing	<20 mins	Left on-screen but no longer used	None

Table 5.5 Independent decision-making task support scenarios

Figure 5.4 compares measured experimental group frequencies of kiosk use with approximations of the control operator's use of the paper-based technical package from table 5.4. It is therefore inferred that the experimental group

[40] After 20 minutes of screen inactivity the kiosk carousel (i.e. screensaver) would commence. Hence, despite variability of individual information usage durations, this provided differentiation between tasks.

reverted to using the paper-based technical package for independent decision-making support.

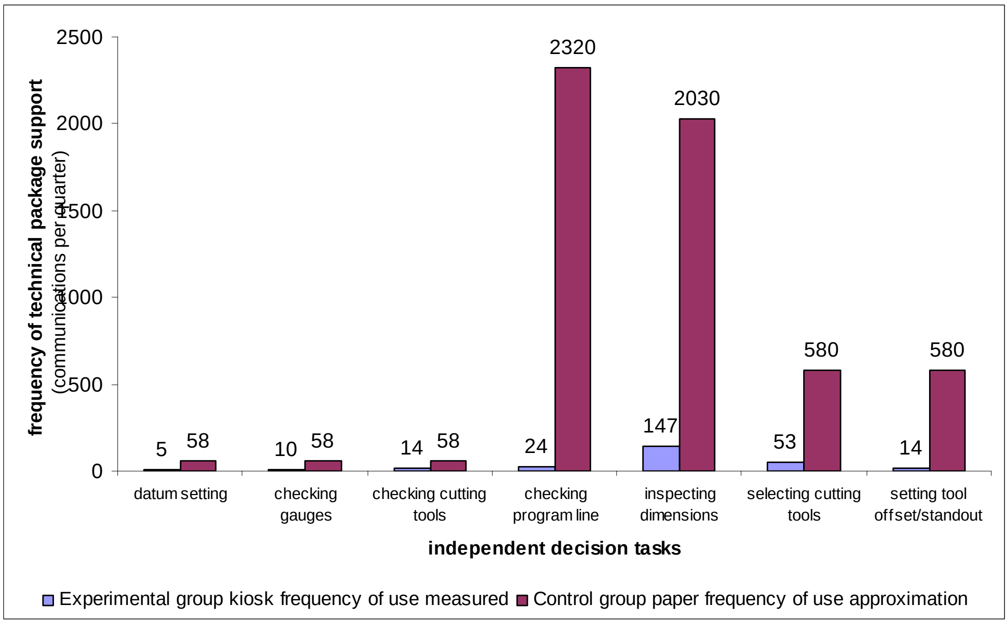

Figure 5.4 Frequency of use of the technical package to support independent decision-making

Table 5.6 demonstrates how control operator task frequency approximations were calculated.

independent decision task	*approximate frequency per job*	*Total no of jobs*	***Calculated task frequency***
datum setting	1	58	58
checking gauges	1	58	58
checking cutting tools	1	58	58
checking program line	40	58	2320
inspecting dimensions	35	58	2030
selecting cutting tools	10	58	580
setting tool offset/standout	10	58	580

Table 5.6 Control operator task frequency calculations[41]

[41] The total number of components manufactured at the control operator's machine tool during the summative evaluation period was 58. As discussed in table 5.2, the first 3 tasks occur once per operation (i.e. job). The 'checking program line' task is highly variable; a frequency of 40 was agreed to be realistic. An average of 35 inspections per job was produced from 20 plug/thread gauge inspections, plus 15 inspections using verniers or micrometers. Finally, ME find a frequency of 10 tool changes per job to be acceptable.

To support this finding, mean durations of technical package use to support each defined task are compared (refer to figure 5.5). This direct comparison suggests that, the kiosk provided less effective support than the paper-based technical package. However, closer examination of the data finds that the log file results are skewed. The root cause was found to be that the log files recorded the time a particular piece of information was on-screen, rather than the duration it was used for. As shown in table 5.5, CNC machinists would leave the information on-screen for some tasks. Hence, whilst they would refer to a detail for just a few seconds, the log file would record usage of several minutes. Although these data are not completely invalidated, no inferences are made about them.[42]

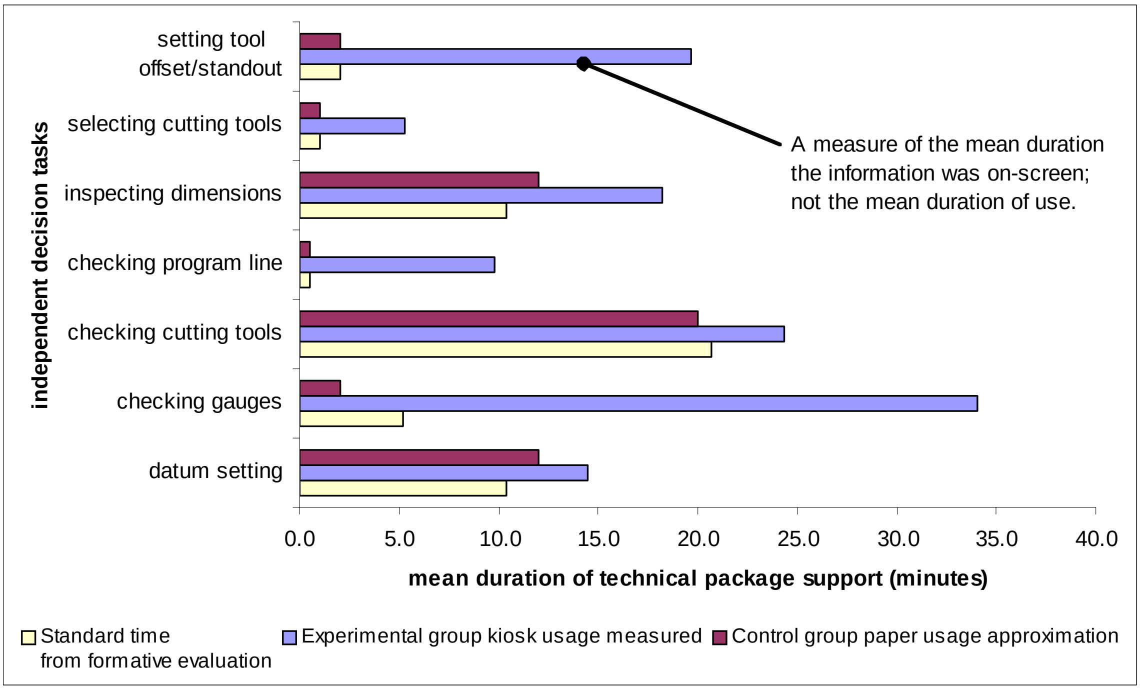

Figure 5.5 Mean duration of technical package use to support independent decision-making

Efficiency data calculated from the mean duration data were therefore also skewed (refer to table 5.4). Hence, figure 5.6 shows that the kiosk-based technical package was inefficient in supporting independent decision-making.

[42] This outcome had not been anticipated prior to data collection.

Yet, qualitative data found otherwise. Qualitative data are therefore discussed to provide more detailed analyses.

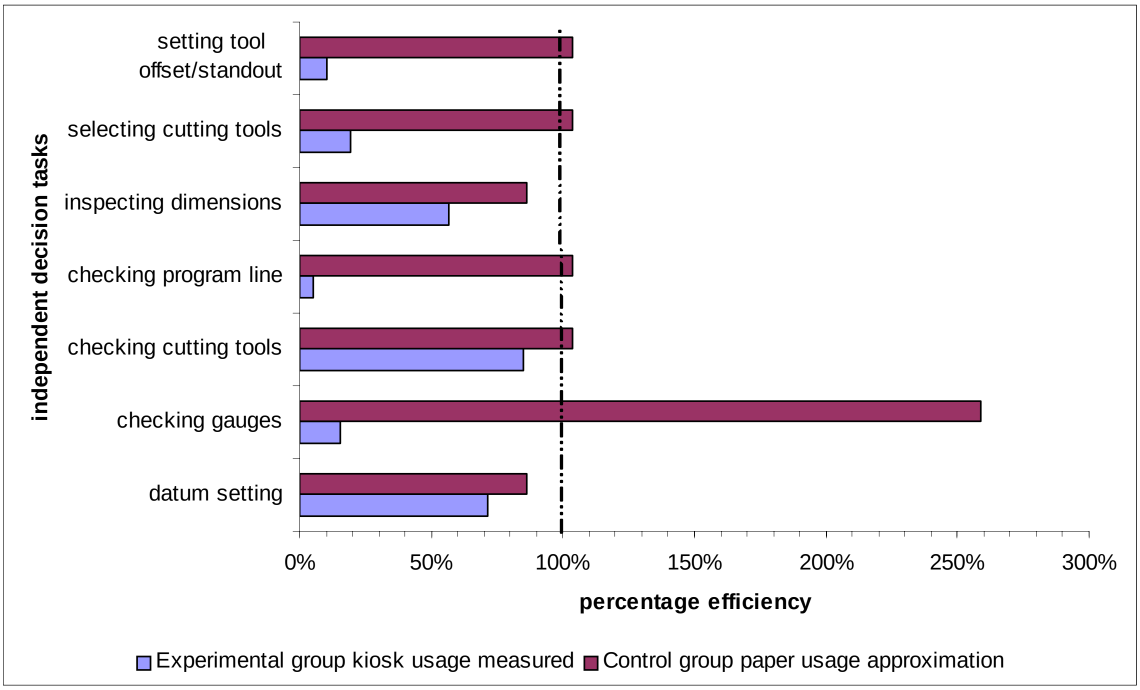

Figure 5.6 Efficiency of technical package support for independent decision-making

Fieldnote data provides a very different picture of the impact of the kiosk.[43] The presentation of engineering drawings and tool drawings via the kiosk was found to be particularly effective. Individuals from the experimental group demonstrated that they could navigate to and from particular pages more effectively and efficiently than finding the same information in the paper documents. With the required information on screen, the machinists could then effectively locate the required detail using zoom and scroll functions.

The program presented on the screen was however, initially presented differently to engineering drawings and tool drawings. A need to scroll the document horizontally was unfamiliar to users and therefore a constraint. The program interface was therefore edited to mimic that of the other types of information. Although, the edited electronic document was satisfactory to the

[43] Fieldnotes are summarised in appendix C.

experimental group, the participants explained that the ability to physically take the paper-based program to the machine tool interface was an advantage that the kiosk could not offer.

A summary of observational data for each independent decision-making task is provided in table 5.7 to clarify the points raised.

Independent decision-making task	Qualitative evaluation of the experimental group
Datum setting	The poor usability of the kiosk program interface limited the use of the kiosk to support this task. However, it is notable that **the paper document offers mobility**. Machinists were observed taking the document to the machine tool interface.
Checking gauge availability	This task was not observed, but was recorded as having occurred with the support of the kiosk.
Checking tool availability	This task was not observed, but was recorded as having occurred with the support of the kiosk.
Checking which line the program is at	As with datum setting, the poor usability of the kiosk program interface limited the use of the kiosk to support this task. This task is central to the tracking of the process; hence **the paper-based program was reverted to for reliability**.
Inspecting machined dimensions and selecting the appropriate gauge	The engineering drawing interface at the kiosk was observed to be preferred to the paper-based engineering drawings. Machinists discussed its use in terms of being "**faster to find the information needed**".
Selecting replacement tools when worn or damaged	As with the kiosk-based engineering drawing interface, the kiosk tool drawing interface was preferred to the paper-based tool drawings for the same reasons.
Setting tool offset/standout	As with the kiosk-based engineering drawing interface, the kiosk tool drawing interface was preferred to the paper-based tool drawings for the same reasons.

Table 5.7 Summary of observational data on kiosk-based technical package support for independent decision-making

It is therefore concluded from the data presented that there is a distinct difference between quantitative measures of kiosk usage and the experimental group's perception of their kiosk usage, with respect to the kiosk-based technical package to support independent decision-making. Whilst the experimental group thought that they were using the kiosk to good effect, the data show that they were not using it as frequently as the paper-based technical package.

5.3 To test hypothesis 2

From chapter 4, hypothesis 2 is defined as:

Hypermedia information systems for CNC machinists can effectively support cross-boundary communications.

5.3.1 Formative evaluation

The CNC machinists of the studied groups were seen to require minimal external support. If all required resources (e.g. tooling, technical package, etc.) are available and no unplanned process stoppages occur, they are able to work independently. Yet, there is commonly a need for informal face-to-face communications with other stakeholders to address process-related issues. Hence, no formal demarcation was seen to exist.

A stakeholder analysis was conducted using data from observation and interviews on CNC machinist interactions with other people at the research setting to produce a list of process stakeholders.[44] These 10 stakeholders are classified by their influence upon the machining process (refer to table 5.8). The research participants also provided qualitative estimates of their frequency of communication with each stakeholder when verifying the list. No differences between the experimental group and control group were found.

[44] The stakeholder analysis is provided in appendix A.

Level of influence upon the process	Stakeholder	Estimated frequency of communication
Primary stakeholders	**CNC machinist (including shiftmates)**	Greater than once a day
	Coach	Greater than once a day
	Cell leader	Once a week
Secondary stakeholders	**ME – Programmer**	Greater than once a day
	Leading hand[45]	Greater than once a day
	ME – Planner	Less than once a week
	Inspector	Less than once a month
External stakeholders	**Tool room**	Less than once a month
	Tool representative[46]	Once a week
	Maintenance	Less than once a month

Table 5.8 Existing process stakeholders

Based upon the data in table 5.8 and the proximity of the stakeholders, a representation of the existing communication boundaries is derived (refer to figure 5.7).

[45] The leading hand is a senior shopfloor operator whose responsibility includes the management of tooling and gauges across the department.

[46] Due to consignment stocking of tooling at the machine tools, the tool rep. liaises with machinists and engineers on a weekly basis.

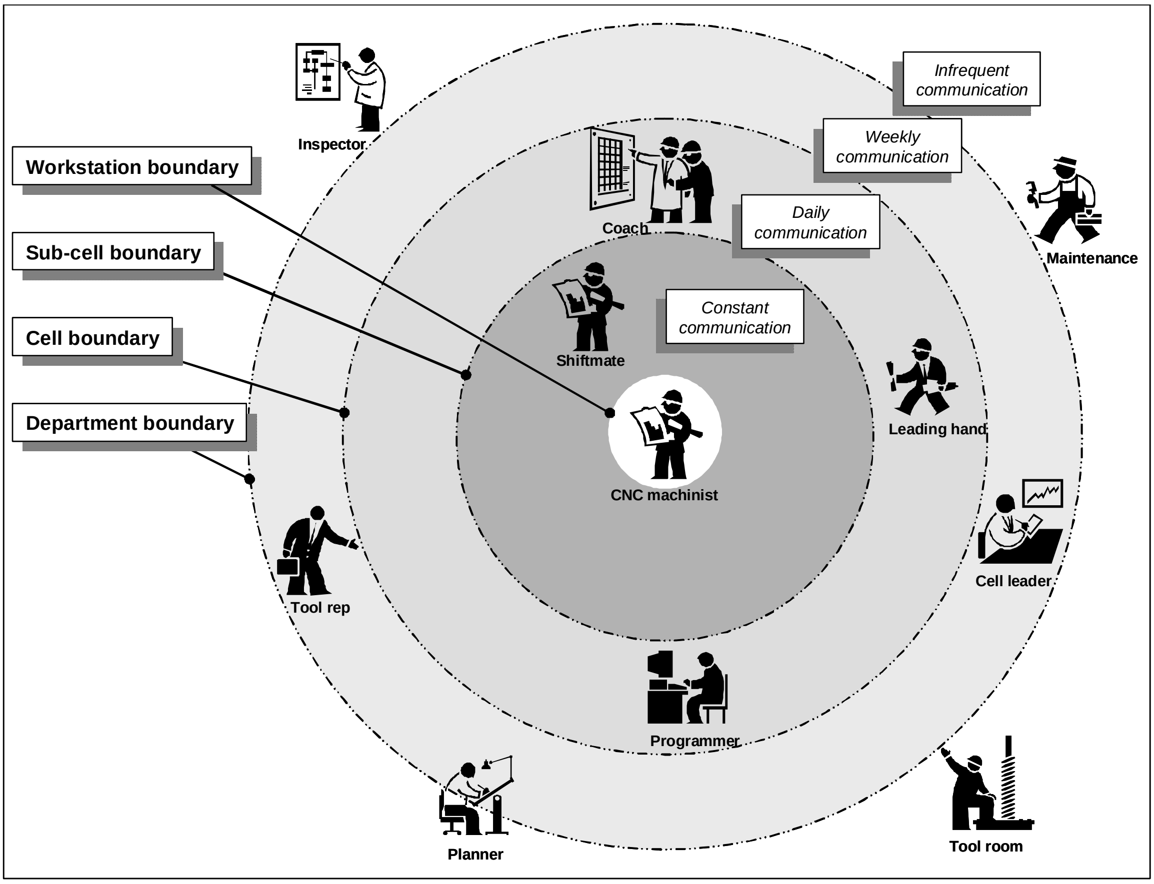

Figure 5.7 A representation of stakeholder communication frequencies and proximity to define CNC machinist communication boundaries

5.3.2 Intervention

To provide for the testing of hypothesis 2, the prototype hypermedia system was developed to also provide a communication tool to support electronic communications with the 10 stakeholders defined in table 5.8.[47] This was achieved using a database-enabled set of web pages via the kiosk user interface.[48]

[47] Appendix B provides a discussion of the development of the prototype hypermedia system.

[48] A major constraint was that the kiosk could not be connected to the company intranet due to bureaucratic limitations. Thus for stakeholders to communicate electronically, they were required to use the kiosk interface.

Effective and efficient navigation of the system by the experimental group was confirmed by usability assessment. Figure 5.8 shows the interface for the kiosk-based communication tool.

5.3.3 Summative evaluation

To test hypothesis 2, evaluation of the effectiveness of kiosk support for CNC machinist cross-boundary communication is discussed. This was achieved by measuring the frequency and duration of kiosk use by the experimental group to support communications with the 10 stakeholders defined in table 5.8.

As previously discussed, results show that the frequency of general kiosk use was low. Hence, use of the kiosk for communication was minimal. Log file data shows just 14 occurrences of *writing* notes on the kiosk in a period of 36 days.[49] Yet there were 74 occurrences of *reading* notes from the kiosk in this time. It is therefore inferred that whilst the experimental group were willing to respond to notes, they were not so keen to initiate on-screen discussion. Table 5.9 provides examples of the recorded kiosk-based communications.[50]

[49] Due to a need to redevelop the communication tool part way through the summative evaluation period, the time in which it was effective was restricted to 36 days.

[50] These notes are unedited, except where names (edited in grey) or serial numbers (blanked out) were originally provided.

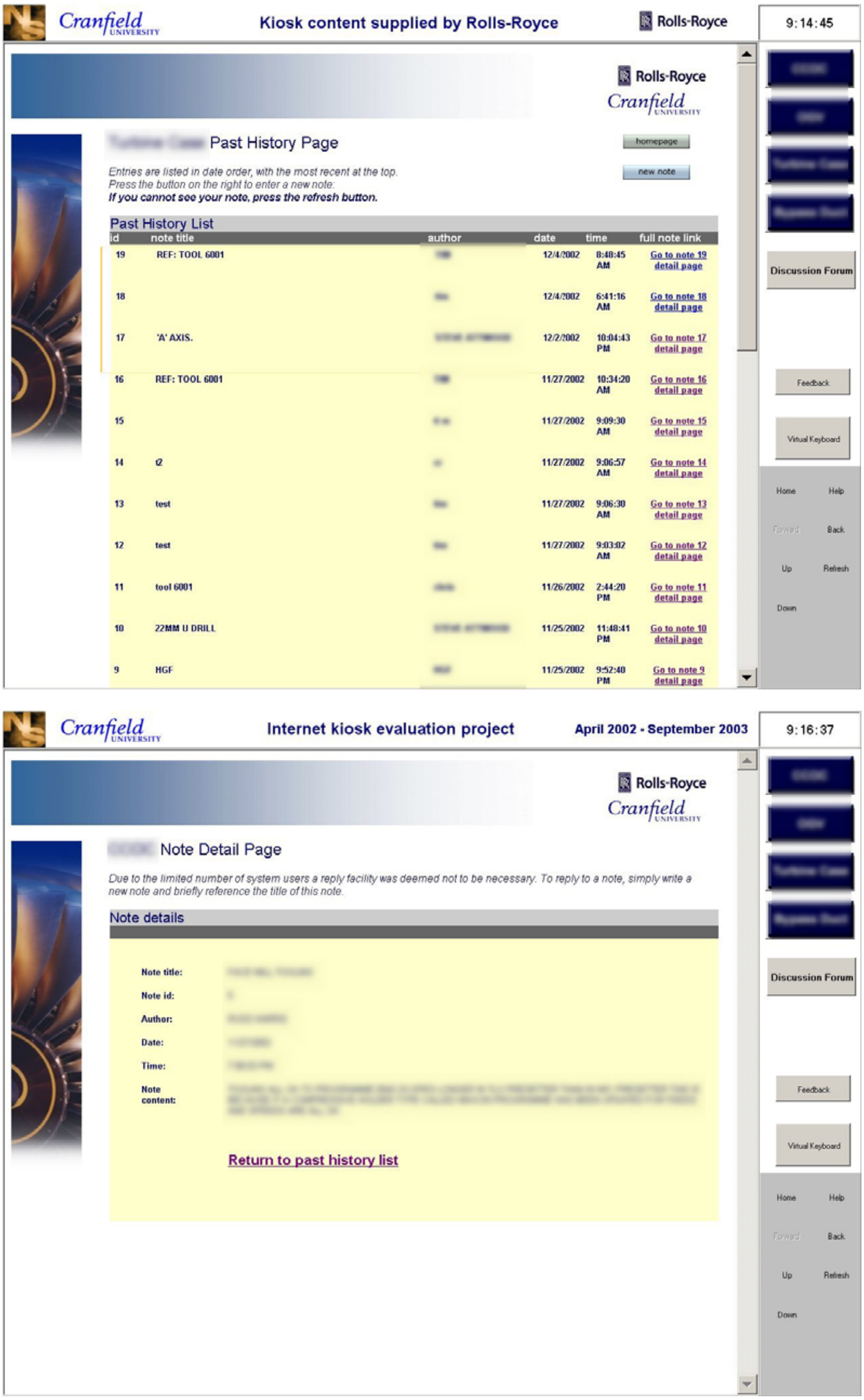

Figure 5.8 The kiosk-based communication tool

Kiosk communication
“MJ8 WOBBLE BROACH IS NOT GOING TO DEPTH .3 OFFSET WAS REQUIRED”
“we have now got a new step drill to try out for op 280 leave word on how it goes ref *programmer 1*”
“ONE DRILL PER COMPT RIT1045825”
▪ “SECO NEED TO STOCK INSERT REF *LEADING HAND*”
“insert will be in the M/C by the end of the week.For now I've ordered 50 and they have just come in.They may be put in m/c just to get sys. up and running for now.”
▪ “tool 1012 a new straight shank cutter to be ordered ref *programmer 2*”
“NEW TOOL IN CHAIN AND HAS BEEN TRYED OUT WITH *PROGRAMMER 2* 25/11/02 ALSO HE WILL OBTAIN A SIX FIGURE CODE”
“NEW 23MM U DRILL REQUIRED.EXISTING ONE DAMAGED.( )”

Table 5.9 Kiosk-based communication examples

Where the kiosk was used for communication, it was used in a limited capacity. Each of these notes is addressed to shiftmates by a member of the experimental group in response to an action, following previous face-to-face discussions with other stakeholders (e.g. a programmer). This a similar dynamic to that observed at shift handover.[51] It is therefore inferred that the kiosk communication tool was used only to *supplement* shift handover discussions with other CNC machinists. Comments by members of the experimental group confirmed that they did not intend to use the kiosk-based communication tool to communication with stakeholders outside of their sub-cell boundary (refer to figure 5.7).

[51] Shift handover was observed during formative evaluation. It is a face-to-face communication where the CNC machinist ending a shift passes on relevant information to the shiftmate beginning the following shift.

Analysis of participants' diary data provides quantitative verification of existing cross-boundary communications and shows the additional impact of the kiosk (refer to figures 5.9 and 5.10).

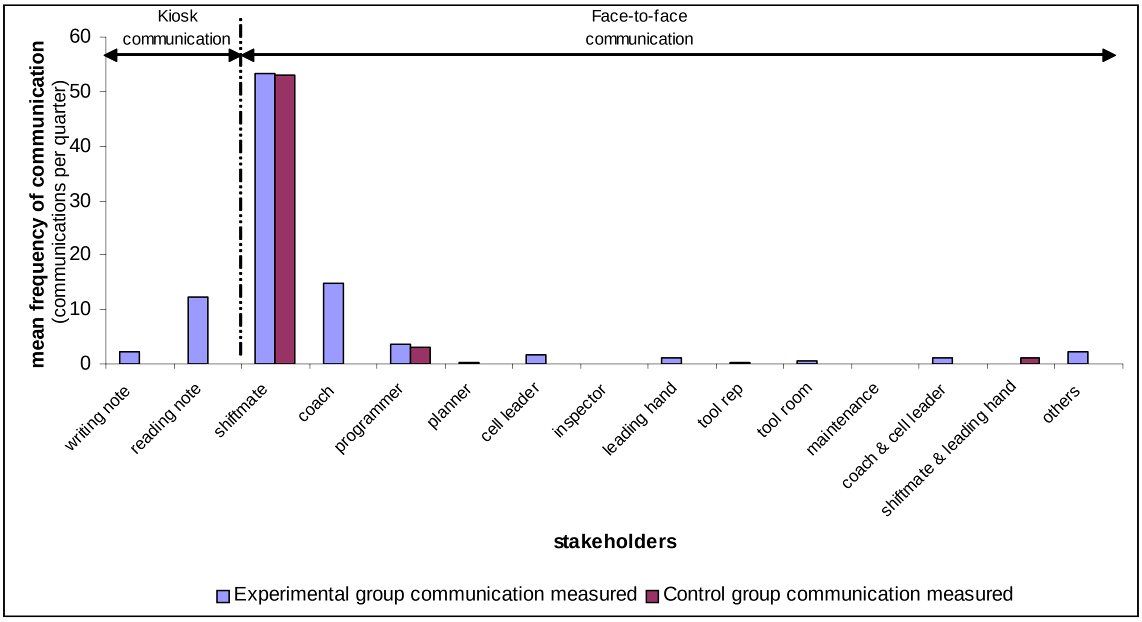

Figure 5.9 Mean frequency of cross-boundary communication[52]

Referring to figure 5.9, face-to-face communication data illustrates the infrequent need to discuss process-related issues with stakeholders other than shiftmates. Yet, figure 5.10 shows that when CNC machinists do communicate with other stakeholders, their discussions are extensive. It is therefore confirmed that CNC machinists rarely need to communicate outside of their sub-cell boundary (refer to section 5.3.1). Nevertheless, the research participants verified that such discussions are typically necessary to address pertinent issues and corrective actions (e.g. to resolve scheduling issues, or to

[52] To provide accurate comparison with the 1 control operator, the total number of experimental group face-to-face communication occurrences are divided by the number of diary respondents (i.e. 3 (3 operators did not return their diaries)). From the log file results, the total number of experimental group kiosk communication occurrences is divided by 6 (i.e. all experimental group operators).

discuss excessive tool wear). Discussions therefore take long enough to sufficiently address the issues raised.

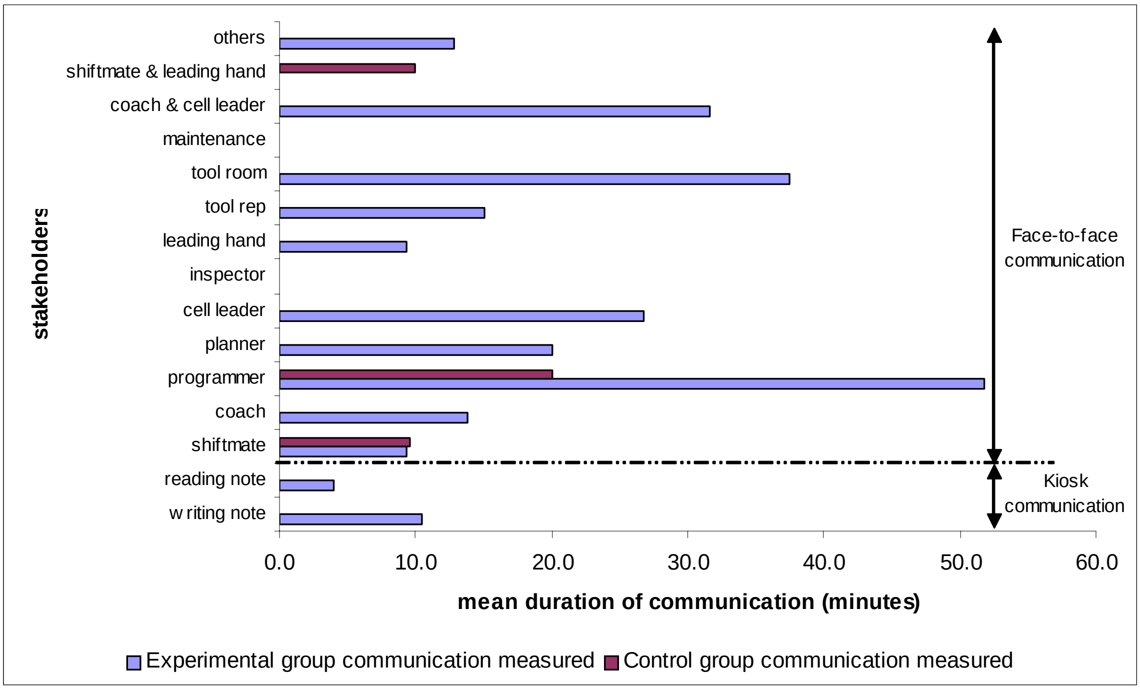

Figure 5.10 Mean duration of cross-boundary communication

Although no formal demarcation exists, it is evident that CNC machinists refer most often to fellow machinists. Hence, it is inferred that the only true communication boundary experienced by CNC machinists is the sub-cell boundary. Other stakeholders and the machinists themselves can freely cross this self-imposed boundary, but with the introduction of the kiosk communication tool the sub-cell boundary was seen to strengthen. Figure 5.11 therefore redefines CNC machinist communication boundaries.

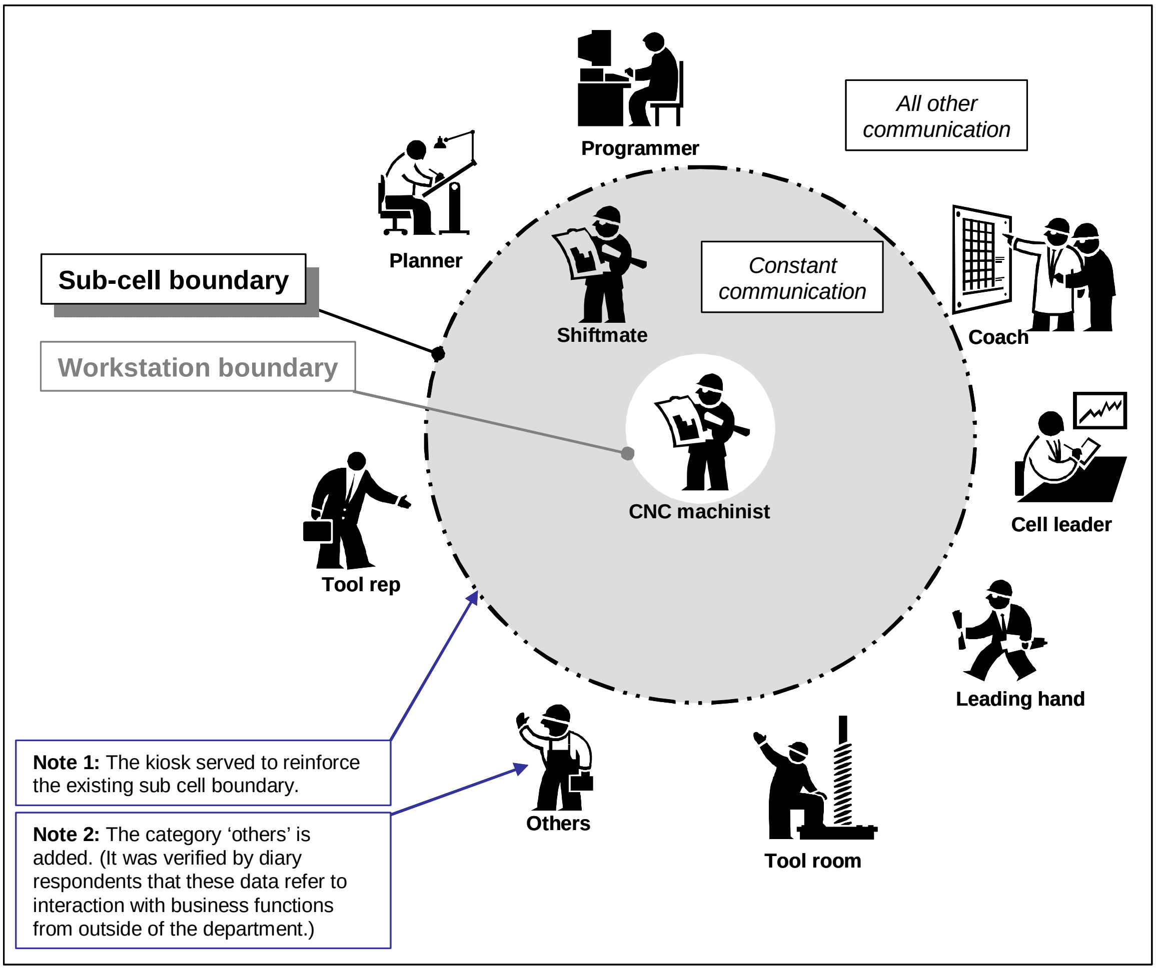

Figure 5.11 Redefined CNC machinist communication boundaries based upon measured frequency of communication

5.4 Chapter summary

This chapter has discussed the findings of an evaluation of existing paper-based and hypermedia-based information systems support for CNC machinist independent decision-making and cross-boundary communications at the selected research setting. To validate these findings, chapter 6 discusses the findings of 3 alternative case studies.

6 Case study results

6.1 Case study 1

6.1.1 Definition of the research setting

Airbus is a global company that manufacture a range of 12 aircraft models for the civil aviation sector. The Broughton site in North Wales manufactures the wings for these products. The research setting was at the LCM (Large Component Manufacture) division, which machines large section skins and spars for the aircraft wings. The processes experience low variation in demand and low product variety. Final assembly operations dictate demand, and therefore production volume. Cycle times average 113 hours, with average set up times of 45.5 hours.

To manufacture such large components, specialist machine tools are employed. 4 machine beds run the length of the facility with 3 CNC machining centres running along each (for an illustration, refer to figure 6.1). Storemen supply a kit of tools to the machine tool, where the CNC machinist sets the machine tool. Stock material (i.e. a billet) is then lifted onto the bed by a dedicated crane operator. The billet is then located and sealed onto the machine bed by the machinist. In process, the machine tool cuts detailed and thin section profiles in the material. Other machine tools of similar design and function are also employed.

Typically there is 1 skilled machinist per machine tool per shift, with a requisite number of storemen, crane operators, inspectors and team leaders (i.e. foremen) in support. The plant operates two 12 hour shifts, with a rotational 4 day week (i.e. 4 days on; 4 days off).[53] Methods and technical support are provided by NC engineers (i.e. manufacturing engineers).

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[53] Hence, there are 4 teams; 1 team per shift.

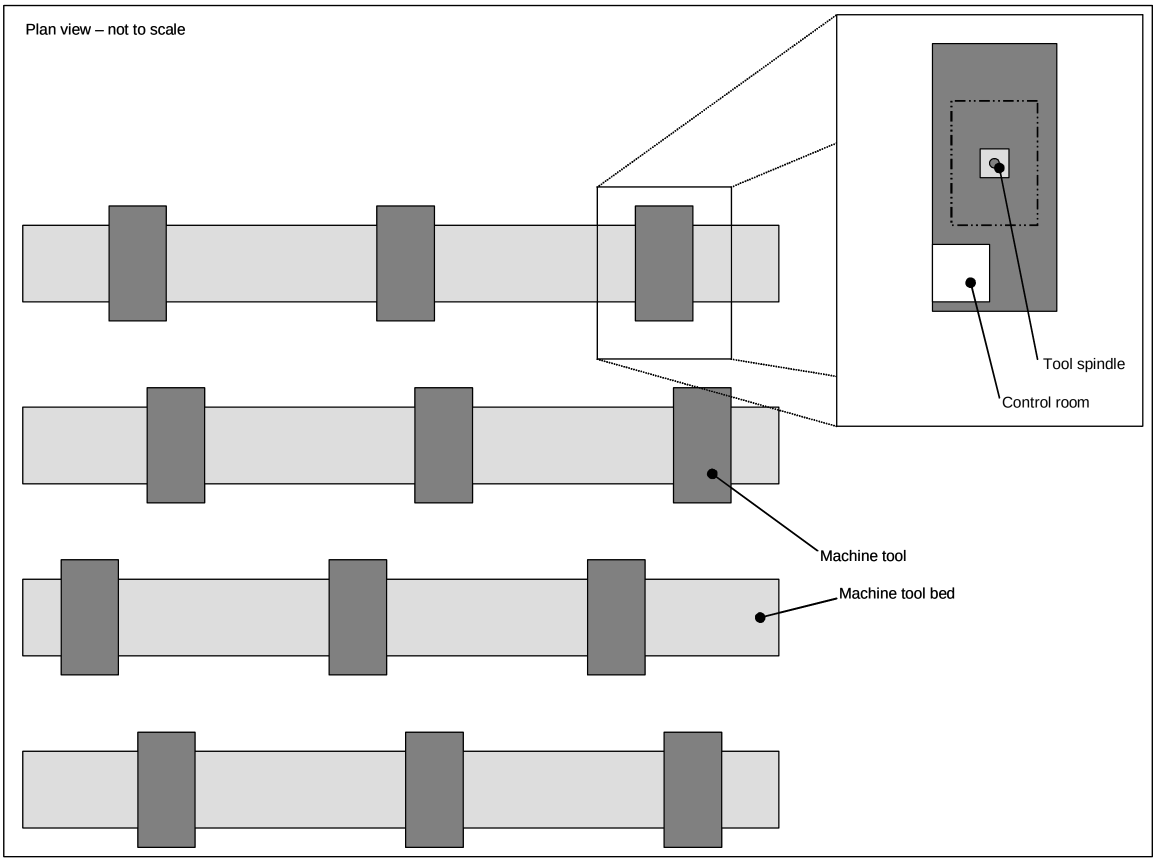

Figure 6.1 Representation of the LCM plant layout

6.1.2 Information systems

Tool setters and CNC machinists use standard operating procedures (SOPs) to set and run the machine tools.[54] These procedures are provided in a set format of detailed sequential instructions, and detail drawings where required. This information is also replicated on PC-based machine tool interface terminals at the control room. The control room features the program interface, control buttons and dials, and video screens and speakers. Cameras and microphones are positioned at the machine tool spindle for detailed monitoring, due to the scale of the machine tool.

Process data are captured at the machine tool control room, and over 250 parameters are stored in a central server. A small proportion of these data are

[54] SOPs are a Quality Assurance requirement.

used for process monitoring and performance measurement. The remaining data are filed for future reference, if in-service fault diagnosis is necessary.[55]

An operator booking system[56] is provided via a bespoke touch screen interface at the machine tool control room. Operators have a series of on-screen buttons that enable the recording of process status. Operators are also encouraged to write details of particular situations to provide sufficient evidence. These data are viewed dynamically by NC engineers, and collated via spreadsheets for daily and weekly process monitoring and performance measurement (e.g. statistical process control data, capacity utilisation data, etc.). The NC engineers and team leaders use these data to control the process and to instigate corrective actions where necessary.

Information systems strategy aims to increase the utilisation of the data collected, to increase performance measurement. This will be enabled by increased systems integration through hypermedia-based interfaces linked to the enterprise resource planning system.

6.1.3 Independent decision-making

The employment of SOPs negates the need for detailed information, such as engineering drawings, tool drawings, or details of the program. Although, CNC machinists did state that engineering drawings are stored locally, but “they have little or no use for them”. The primary purpose of the SOPs in this production system is to provide specific set up information to limit variability, thereby ensuring repeatability.

Nevertheless, some flexibility in machine tool operation was observed. CNC machinists are required to verify program execution. Where necessary, the

[55] Due to the high cost of in-service component failure, traceability is of paramount importance in the aerospace industry.

[56] The booking system is based upon a conventional job/batch card system, where each operation is recorded (i.e. stamped) as complete. The observed system has the capability to record a greater number of operation parameters.

machinist must use discretion to edit blocks of the program and control the cutting speeds, feed rates and other conventional process parameters in reaction to particular circumstances at any given time (e.g. the machinist finds surface finish to be poor and therefore reduces the feed rate). Hence, the process is reliant upon CNC machinists' skill to compensate for the process (Sauer, et al., 2000).

In conclusion, the process constrains operator input to the extent that the CNC machinist solely performs a monitoring function. Hence, the only task from table 5.2 observed to be supported by the information system (i.e. machine tool interface) was '*checking which line the program is at*'.

6.1.4 Communication boundaries

The process monitoring system, via the booking system provides a formal communication process. The machinists have a limited number of options to record process status (e.g. 'waiting tools' or 'planned preventive maintenance', etc.). Operator comments provide an explanation of the data. The NC engineer can then interpret these data to produce an understanding of process status, based upon process knowledge[57]. Hence, the information system constrains the CNC machinist to the control room, to focus upon direct process monitoring. Meanwhile, the NC engineer performs more detailed off-line analysis. The aim of this system is effective incremental performance improvement, enabled by extensive data collection.

The requirement for such a formal system is partly attributed to the rotational shift system in operation. The rotation of operators and team leaders every 4 days creates the need for traceability, as corrective actions commonly span several shift handovers.

[57] The dependence upon the NC engineer's knowledge for interpretation of data cannot be overstated. The engineer adds descriptive meaning to the data, based on experience.

Distinct demarcation was observed, due to the requirement for formal reporting procedures. CNC machinists were therefore observed to have communication boundaries limited to the team leader (face-to-face) and the NC engineer (electronically). Nevertheless, the system is dependent upon initial accurate reporting by the machinists.[58]

6.2 Case study 2

6.2.1 Definition of the research setting

Kenard Engineering is a first tier supplier to a range of industries, including aerospace. Customers include Rolls-Royce plc. The research setting was at Kenard's Dartford (Princes) site, which employs CNC turning centres, flexible machining centres[59] and machining centres[60]. Batch manufacture is employed to produce a wide product range in various materials. Production volumes are balanced, with low variation in demand but high product variety, due to a varied but established customer-base.

The plant operates two 12 hour shifts, in a 4 day week (i.e. 4 days on; 3 days off). Highly skilled CNC machinists are employed to maintain production flexibility. Other functions include skilled inspectors, section leaders (i.e. foremen) and production engineers. CNC programmers and planners provide the production methods. There are approximately 50 employees across 2 sites in Dartford.

6.2.2 Information systems

Kenard Engineering operates a bespoke information system named KIDS (Kenard Information Data-collection System). This windows-based system

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[58] It is noteworthy that an NC engineer discussed a reticence by machinists to add comments to the recorded data. However, incremental improvements as a result of detailed data analysis demonstrated the benefit, resulting in an increase in the use of this function.

[59] Continuous machining is enabled by off-line tool and fixture changing.

[60] This type of machine is capable of turning and milling operations.

was initially developed in 1996 to replace a batch (i.e. job) card database, from which paper-based batch cards were generated. KIDS Batch[61] now presents an electronic batch card that provides the same information as was previously required (e.g. part number, batch number, operational sequence, etc.). To replicate the conventional stamping (i.e. booking) procedure, operators use a swipe card to uniquely identify that they have completed a particular operation.

KIDS Batch also provides links to manufacturing instructions. Manufacturing instructions include engineering drawings, program code, tool drawings, photographs of the component, and simulations of cutter paths. The information systems hardware used at machine tool workstations is a standard desktop PC with a keyboard, mouse and printer. The standard windows interface is provided; operators therefore are not restricted in their use of the system. They can also view the company intranet, which has various current and historical information including curriculum vitae-style web pages for each employee.

Since its conception, KIDS has evolved to provide integrated functionality across the business, including manufacturing resource planning (MRP) and dynamic customer order status information through the company website. Performance measurement is facilitated by data collected via KIDS, and input into data-enabled spreadsheets. Kenard Engineering believes KIDS offers them a distinct competitive advantage through its unique functionality, which is continually developed.

6.2.3 Independent decision-making

The KIDS Batch application provides all information required to support independent decision-making. However, it was found that operators printed specific information as required (e.g. engineering drawings). The common

[61] KIDS Batch is just one application in a suite of integrated business tools. For example, KIDS Queue provides machine tool queuing information.

reason given was that paper-based information offers the ability to view more information at once and locate particular details faster.

The independent decision tasks identified in table 5.2 are discussed in turn to define whether each is supported by KIDS.

- *Datum setting*: This is an essential task in the set up of the types of machine tools employed. This task is supported by the on-screen program window.

- *Checking gauge availability*: Gauges are stored centrally in the inspection area. Machinists therefore collect gauges from the store as required. The information indicating which gauges are required is provided by the on-screen engineering drawings and batch card. Whether gauges are collected during set up or at intervals in the operation is at the discretion of the operator. Hence, this task does not exist in this setting. However, it is redefined as '*collect gauge(s) from store*'.

- *Checking tool availability*: Tools are also stored centrally. These are delivered to the machine tool during set up. This task does not therefore exist.

- *Checking which line the program is at*: This is not necessary in this setting. Vericut software is used by CNC programmers to verify all programs prior to download to the shopfloor. Operators therefore entrust the machine tool to run without error. The provision of the cutter path simulation supports the machinists' confidence.

- *Inspecting dimensions*: Inspection usually occurs at the end of a complete operation.[62] First offs[63] are required to be inspected by dedicated inspectors.

[62] Relatively short cycle times determine that inspections at intervals in the process are not necessary.

[63] The first-off is the first component in a batch. It is fully inspected to further verify the process.

Subsequently, machinists will inspect dimensional accuracy and edit the program if and when required.

- *Selecting replacement tools*: This task is supported by tool drawings where required. Although new tools are delivered at set up, tool wear can occur in process. The skill of an individual machinist will determine tool life.

- *Setting tool offsets*: As discussed in chapter 5, this task is paired with the previous task. It is also supported by tool drawings.

6.2.4 Communication boundaries

Although a formal hierarchy exists, there is no demarcation in this setting. The small scale and close proximity of all stakeholders ensure effective and efficient face-to-face communication. KIDS offers a comments field, where operators can provide feedback on the process. However, it is very rarely used. Equally, the company suggestion scheme is not commonly used because issues are raised as they occur on a face-to-face basis for “rapid” resolution. Thus, no communication boundaries exist.

6.3 Case study 3

6.3.1 Definition of the research setting

The third case study was conducted at Roll-Royce plc, in another division to that of the evaluation setting discussed in chapter 5. The components manufactured at this setting are large shafts for the compressor systems of gas turbine engines. CNC turning centres and conventional machine tools such as jig boring machines are employed. Production volumes fluctuate, with low variation in demand but high product variety.

Highly skilled CNC machinists are employed across three 8 hour shifts. Some machinists are dedicated to particular CNC machine tools, whilst others are required to operate both conventional machine tools and CNC machine tools. Some machine tools require shopfloor programming; however this is restricted to specific operations and machine tools. The CNC machinists report to a cell leader. Production methods and planning are provided by manufacturing engineering (ME), which consists of production planners and CNC programmers.

6.3.2 Information systems

The set of manufacturing instructions used are referred to as the 'technical package'. The information format does, however, vary from the technical package observed at the evaluation setting. The operator requests a copy of the manufacturing instruction (MI) [64] and manufacturing (i.e. engineering) drawings from a central drawing store. These A4 and A3 paper sheets are stamped for quality assurance purposes and arranged at the workstation by the operator. Stored in folders at the workstation are tool drawings and an A4 print of the part program.[65]

As at the evaluation setting, post-processed programs are delivered to the shopfloor via a direct numerical control (DNC) system. The CNC machinist uses PC-based software to select and view the required programs. A key difference between this setting and the evaluation setting is that here there is 1 DNC terminal per workstation; whilst at the evaluation setting DNC terminals are shared at a central location.[66]

6.3.3 Independent decision-making

The technical package described in section 6.3.2 provides support for independent decision-making. Nevertheless, it was stated that the paper print of the program is not used. Instead, the CNC machinists refer to the program file at the DNC terminal. When asked whether they can also do so at the

[64] The MI is a basic description of the required operation, consisting of a single sheet of A4 paper.

[65] This is very different to the printed program seen at the evaluation setting. The programs are much shorter and can be printed on just a few A4 sheets. The system used to generate the large program prints at the evaluation setting is no longer used at this setting.

[66] The importance of this distinction is clarified in section 6.3.3.

machine tool interface, a machinist demonstrated that he can, but stated that he preferred to use the DNC terminal because the PC is more user-friendly and the text is larger than at both the machine tool interface and the paper document. An additional complication is that separate approval must be sought to print the paper-based program when updated. Hence machinists would rather not use it.

Discussion with the ME team leader identified that the DNC application is capable of storing most types of electronic file. Hence, other electronic documentation (e.g. drawings, photographs, movie clips, etc.) could be stored with the program for reference by CNC machinists.[67] Indeed, ME provide a still image of a completed verification simulation via the DNC terminal to demonstrate to machinists that the program is proven.[68]

The independent decision tasks identified in figure 5.2 are discussed in turn to define whether each is supported by the technical package.

- *Datum setting*: This task is supported by viewing the program at the DNC terminal and the paper-based MI.
- *Checking gauge availability*: Gauging is stored centrally. Machinists collect gauges from the store as required. This task does not therefore exist.
- *Checking tool availability*: Tools are also stored centrally via a tool management system. Machinists collect tools from the system as required. Data are collected by the tool vendor to periodically restock the system. This task does not therefore exist.

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[67] The author has seen the full capabilities of the DNC software demonstrated by the vendor. However, Roll-Royce made a strategic decision to initially limit content (The DNC system was implemented less than 3 years ago).

[68] Unlike the evaluation setting, program verification software is run by ME for <u>every</u> program prior to delivery to the shopfloor. At the time of the evaluation, that setting had not fully implemented this technology.

- *Checking which line the program is at*: As discussed, the machinist refers to the program at the DNC terminal.

- *Inspecting dimensions*: The A3 paper manufacturing drawings are referred to for this task. Magnets are provided to locate the documents on the machine door or at metal boards at the work bench.

- *Selecting replacement tools*: This task is supported by tool drawings where required.

- *Setting tool offsets*: As discussed in chapter 5, this task is paired with the previous task. It is also supported by tool drawings.

6.3.4 Communication boundaries

As observed elsewhere, no formal demarcation exists at this research setting. Face-to-face discussions are enabled by a close proximity of all stakeholders. Additionally, the DNC software enables machinists to attach comments to the on-screen program. One example of note writing seen was where a machinist had written in red: “do not run this program”. However, this function is not widely used. Indeed, the ME team leader cited information technology literacy as a problem. Whilst some CNC machinists use PCs outside of work, others do not.

6.4 Chapter summary

This chapter discusses the findings of case studies conducted to validate the evaluation results. A discussion of the overall research results is provided in chapter 7 to provide conclusions about the impact of hypermedia-based information systems upon CNC machinists’ independent decision-making and cross-boundary communications in the studied environments.

7 Discussion and conclusion

The aim of this research is to evaluate the use of hypermedia information systems to support CNC machinists. By comparing and contrasting this technology with existing paper-based information systems, the two main project objectives are fulfilled:

- A contribution to the wider body of knowledge is made from the research findings, with respect to information systems support for CNC machinist independent decision-making and cross-boundary communication.

- The research sponsor is informed of the business implications of implementing hypermedia information systems for CNC machinists to enable strategic alignment of shopfloor information systems with production system requirements.

This chapter provides a discussion of the research findings to meet these objectives.

7.1 Discussion of the research findings

7.1.1 Independent decision-making support

Hypothesis 1 was stated as:

Hypothesis 1: Hypermedia information systems for CNC machinists can effectively support independent decision-making.

The evaluation findings show that the prototype hypermedia-based technical package was used by CNC machinists to support independent decision-making for each of the 7 tasks identified at that research setting. Indeed, the experimental group demonstrated that they were able to navigate the hypermedia-based technical package faster than the paper-based technical package. Nevertheless, quantitative data show that the hypermedia-based system was infrequently used for productive work. Instead, the CNC machinists were found to revert to using the paper-based system.

This phenomenon was also observed in the second case study (refer to section 6.2.3). CNC machinists at this research setting commonly print on-screen information for reference. It was stated that although their electronic information system is well established, the technology does not offer as much usability as paper documents. This is particularly so for engineering drawings.

CNC machinists' preference for paper-based information to support independent decision-making is evident. Whether this is due to machinists reverting to well established norms is not known. Based upon the evidence presented, it is however arguable that neither paper-based nor electronic information is a CNC machinist's primary source of reference. Instead tacit or experiential knowledge is what a machinist refers to first (Hazlehurst, et al., 1969; Taylor, 1978; Böhle, et al., 1994; Tuominen, et al., 1989; Kasvi, et al., 1996). Information is merely a supplementary form of support when the machinist cannot recall detail (Kasvi, et al., 1996). This raises the question of whether CNC machinists require information that is specifically designed to support independent decision-making in environments such as those observed.

Electronic information systems are stated as a requirement of the skill-based paradigm (Kidd, 1992; Mårtensson and Stahre, 1992). Using Hirsch-Kreinsen's organisational representations (1993), each of the studied research settings can be classified as having "limited divisions of labour" (refer to figure 2.2); whilst, using Bengtsson and Berggren's model (1989), the observed CNC machinists can be classified as "production cell workers". The studied work organisations do not therefore conform to the specifications of the skill-based concept (Hirsch-Kreinsen, 1993; Mårtensson and Stahre, 1992). Hence, the argument for better information support for improved independent decision-making in a skill-based environment need not necessarily apply in a CNC machining environment with limited divisions of labour.

The reviewed literature does not distinguish between the information requirements for CNC *planning* (i.e. programming) and *execution* tasks (Taylor, 1978; Sauer, et al., 2000). In a skill-based environment, shopfloor programming is stated as a core competence (Schultz-Wild, 1993). CNC machinists in such an environment therefore perform both *planning* and *execution* tasks. However, in an environment with limited divisions of labour, CNC programmers perform *planning* tasks, whilst CNC machinists perform *execution* tasks, as observed (Hazlehurst, et al., 1969). Thus, based upon the findings of this research, there is no requirement to redesign information with the aim of better supporting independent decision-making for CNC program *execution* tasks.

7.1.2 Cross-boundary communication support

Hypothesis 2 was stated as:

Hypothesis 2: Hypermedia information systems for CNC machinists can effectively support cross-boundary communications.

The evaluation findings show that the hypermedia-based communication tool was used in a limited capacity by CNC machinists to supplement face-to-face discussions with shiftmates at that research setting. The experimental group provided detailed information via the hypermedia-based communication tool, which was also referred to. Nevertheless, quantitative data show that the hypermedia-based communication tool was infrequently used. Face-to-face communications with other stakeholders continued.

Again, this phenomenon was also observed in the second and third case studies. CNC machinists in these environments communicate on a face-to-face basis, despite the availability of comment fields attached to electronic documents on both of their information systems. It was stated in the second case study that even though their electronic information system is well established, the comments field is rarely used.

In the first case study, a different dynamic was observed. The data collection system used requires CNC machinists to record process status periodically via a touch screen at the machine tool. This provides process control and performance measurement. The result is a reduced role for the CNC machinists, whilst problem-solving and management of the process become the responsibility of other stakeholders. This system meets the objectives of that company, but is arguably a more Tayloristic model (Wilkinson, 1983) than observed elsewhere during this research.

In all but one of the observed environments, there is little or no demarcation between different stakeholders (Wall, et al., 1990). The close proximity and mutual understanding of the importance of each other's roles means that face-to-face communication is sufficient for effective problem-solving.

The implementation of the hypermedia-based communication tool at the evaluation setting, served only to reinforce a communication boundary around the studied CNC machinists. The CNC machinists stated a clear intention to retain their knowledge by using the hypermedia-based communication tool to pass information only between themselves. This is a protectionist behaviour that is evident across the metal cutting industry, influenced by continual threats to job security (Rose, 1978; Benson & Lloyd, 1983). Thus, on one hand, it could be argued that CNC machinists are not ready to voluntarily impart their tacit knowledge to other stakeholders. However, on the other hand, the overriding research finding is that in an organisation with minimal demarcation and a close proximity of stakeholders, face-to-face communication is most effective. The need for alternative modes of communication is therefore negated, as no formal communication boundaries exist.

7.1.3 Summary of the research findings

In testing hypothesis 1 it is found that in CNC machining environments with *limited divisions of labour* (Hirsch-Kreinsen, 1993) the type of media used to present manufacturing information does not impact the effectiveness and efficiency of CNC machinists' tasks. CNC machinists' primary source of reference is their tacit experiential knowledge (Kasvi, et al., 1996; Böhle, et al., 1994). Hence, if manufacturing information is provided in a usable format, CNC machinists will adapt to either paper-based or electronic media without impeding productivity. Each research setting is summarised in this context to confirm this point:

- At the evaluation research setting, CNC machinists were found to accept and use the prototype information system, but quantitative data show that it was no more effective and efficient than the existing paper-based system.

- At case study 1, *extensive divisions of labour* were observed (Hirsch-Kreinsen, 1993). This contrasting environment is discussed to show that standardised information systems limit CNC machinists to precise tasks. It is arguable that a change in media would have a greater impact in such environments because CNC machinists are more reliant upon information than in environments with limited divisions of labour.

- At case study 2, CNC machinists use an established electronic information system. It is used extensively, but CNC machinists are selective in how they use it. The system is accepted as a supplementary task support resource by CNC machinists and management.

- At case study 3, the introduction of PCs at workstations for other purposes has enabled CNC machinists to adapt to the technology. CNC machinists are able to use an electronic copy of the part program as well as the paper-based document. The electronic document was shown to be more usable, but does not improve productivity as it merely supplements machinists' knowledge *and* information at the machine tool interface.

In testing hypothesis 2, it is found that in CNC machining environments with *limited divisions of labour*, no formal communication boundaries exist. Mutual understanding of co-workers' roles and freedom of movement enables effective and efficient face-to-face communication (Seppälä, et al., 1989). Alternative methods of communication are considered inefficient in comparison, and are therefore rarely used. Each research setting is summarised in this context to confirm this point:

- At the evaluation research setting, freedom of movement enables CNC machinists to conduct face-to-face discussions when and where required. Hence, alternative modes of communication are not considered necessary. The prototype information system was however used by CNC machinists to record specific detailed information for future reference, thereby demonstrating a wider benefit of such a resource.

- At case study 1, *extensive divisions of labour* limit cross-boundary communication to formal reporting of process status via an electronic interface. Such barriers to communication again provide a contrasting perspective to the findings of other cases.

- At case study 2, the established electronic information system has a provision for on-screen communication, but it is rarely used. The small scale and layout of the environment ensure effective and efficient face-to-face communication.

- At case study 3, CNC machinists are able to annotate documents electronically. However, this is an informal capability that is not widely used. The layout of the machine shop promotes effective and efficient face-to-face communication.

These research findings therefore illustrate that CNC machining environments with limited divisions of labour operate flexible work structures. Hence, the provision of electronic information systems to supplement experiential knowledge and face-to-face communication does not negatively impact production. A case for the implementation of such systems therefore exists.

7.2 Business implications

This research finds that the implementation of electronic information systems such as the kiosk prototype would not have a detrimental impact upon production in a CNC machining environment with limited divisions of labour. Indeed, such a system would enable strategic alignment of the shopfloor with the technical community as required. It would also necessitate the reengineering of existing information processes to ensure an effective transition to the new system. For example, the need to create, store, distribute and control paper-based information would become virtually obsolete. Hence, facilities such as drawing stores would be eliminated to provide a substantial cost saving to offset implementation costs. Thus, the actual cost benefit of such systems should not be measured in terms of increased productivity, but in terms of reduced administrative costs. Indeed, McLean (1990) and Willis, et al. (2002) highlight the inefficiencies of managing paper-based documentation on such a large scale.

Appendix D provides estimated cost benefit analysis of a potential kiosk-based information system implementation at a CNC machine shop such as the evaluation research setting. Based upon observational data from that site, the total cost of the existing paper-based system is estimated as £96,000 per annum, compared with an estimated annual cost of £46,000 for a networked kiosk-based information system. Hence, the estimated annual cost saving is £50,000. With an estimated implementation cost of £158,000, the payback for such a system would be 3 years. Assuming that all Rolls-Royce machine shops are of the same size, equivalent cost savings are possible and a 3 year payback would be applied across the organisation.

Furthermore, the sponsor must also consider that the findings of this research suggest that the fundamental principle of socio-technical systems theory is upheld: the need for joint optimisation of the technical *and* social systems (Hyer, et al., 1999). This is best illustrated by the findings of case study 1, where the standardisation and communication barriers of the information system have a detrimental impact upon the social system. Rolls-Royce must therefore develop the social environments in parallel with information systems to realign production with the technical community whilst maintaining flexible work structures.

7.3 Methodological issues and project constraints

As in the case of most real world research (Robson, 1997), constraints were placed upon this research. The project experienced technical, organisational and methodological issues. Hence, the reader should consider the following influences upon this research when interpreting the research findings.

- Prior to the development of the prototype information system, discussions with the sponsor found that organisational constraints would have placed a prohibitively long timescale on the approval and installation of a connection to the company intranet for the kiosk. Such a connection would have been desirable to enable networked electronic communication with other stakeholders, and thus test hypothesis 2 to a greater extent by significantly changing the mode of cross-boundary communication. A network connection was not sanctioned, and the testing of hypothesis 2 was limited.

- During the summative evaluation period the technical support of the kiosk was the sole responsibility of the researcher.[69] Logistical issues prevented unlimited support. This constraint was exposed by a combination of power supply failure and the security of the kiosk[70] to cause breakdowns, which led to periods without kiosk use. This combined with increasing software instability to frustrate users. However, individuals did persevere, which enabled the collection of reliable but minimal data.

- To overcome the inappropriateness of direct work study methods, alternative solutions were sought. The methods employed were unobtrusive but limited. Both the diaries and kiosk log files highlighted an inability to accurately measure actual events in detail that would provide a complete depiction of all events. This is however a common compromise in real world research.

- The most significant influence upon the core evaluation results was that the experimental group were able to use the existing paper-based information as well as the kiosk during the summative evaluation period.[71] The departmental quality assurance requirement enforced the availability of auditable (paper-based) information to the group at all times. The outcome was that the experimental group reverted to using the available paper-based

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[69] Refer to Appendix B for further information.

[70] The kiosk enclosure housed a standard pc unit with a standard reset switch. However, the enclosure was locked for security purposes, thereby making the switch inaccessible to all but the researcher.

[71] Refer to section 5.2.3.

information, which is evidenced by the low kiosk usage data. If it had been possible to restrict the experimental group to using only the kiosk-based information, a larger amount of kiosk usage data would have been available.

- Finally, the impact of the selected kiosk development method should not be underestimated. [72] Resource constraints dictated that the system development and the evaluation research were conducted as a single project. Hence, the project as a whole was complex and difficult to control. Retrospectively, separating the two tasks into distinct projects would have enabled better control of each to better manage previously discussed issues. For example, developing the kiosk away from the workstation prior to implementation may have produced a more stable interface.

In summary, the combined complexity of the selected research methodology and chosen technology produced particular issues that may have otherwise been avoided. Future researchers should pay particular attention to these issues when planning similar research; hence corresponding recommendations are made in section 7.5.

[72] Refer to Appendix B.

7.4 Research contribution

This research provides two core findings. Firstly, where a production environment dictates that CNC machinists perform only CNC program execution tasks (i.e. where limited divisions of labour exist); there is no requirement to redesign information with the aim of better supporting independent decision-making tasks. Secondly, where there is no demarcation between stakeholders in a CNC machining environment, there is no requirement to provide information systems support for cross-boundary communications, because no formal boundaries exist.

The primary contribution of this research to the wider body of knowledge is therefore that in CNC machining environments with limited divisions of labour there is no requirement to design information systems to improve the support of independent decision-making and cross-boundary communications.

Nevertheless, the fact that hypermedia information systems do not negatively impact CNC machinists' performance provides a more widely relevant contribution. This finding enables a broader range of research to be pursued in this field, with knowledge of CNC machinists' acceptance of the technology.

Considering the constraints placed upon this research, supplementary contributions to knowledge are offered. The real world context of the core evaluation activity produced technical and organisational limitations, which were particular to that environment. Although the selected research methodology overcame many constraints, this research highlights the risks of researching information systems development in the real world. External influences, such as power failures and information up-issues, necessitated system support issues. The reader should therefore consider the limitations experienced here, when undertaking information systems research in similar environments. Particular attention should be drawn to the limitations of users and the external pressures they faced. Relevant recommendations are made in section 7.5.

Data collection was constrained. Diaries were dependent upon the goodwill of the participants; whilst the log files generated data that required extensive analysis to extract meaning. It is considered that work study techniques would have achieved greater accuracy, but were not possible due to industrial relations issues and time constraints.[73] Hence, the reader should carefully consider data collection techniques when undertaking evaluation research in a shopfloor environment.

7.5 Recommendations for further research

This research examines two distinct phenomena in the same context: CNC machinists and hypermedia-based information systems. The research findings encourage continued research to explore these phenomena further.

Referring to the literature reviewed in chapter 2, there is a range of socio-political influences upon today's CNC machinists. National context is also important (Badham, 1994). Much of the previous research to understand and improve the role of CNC machinists was conducted in Germany, and was necessitated by the new competitive pressures of reunification (Hirsch-Kreinsen, 1990). The research reported here is UK-based and therefore found no evidence of the skill-based paradigm developed in Germany and other European countries. With UK manufacturing facing its own competitive pressures (Porter, 2003), there is a need to better understand the role of the CNC machinist in this national context to develop and therefore better utilise this valuable resource. It is therefore recommended that future researchers:

- Research the current role of UK-based CNC machinists and the work structures within which they work to provide a baseline for improvement;
- Research future CNC manufacturing work structures;
- Research future CNC machinist job content and skill requirements.

This research will therefore enable the development of shopfloor work structures and competences to use new technologies such as hypermedia.

[73] As discussed previously, work study would have necessitated lengthy periods of observation.

Meanwhile, researchers should also continue to develop information systems to meet the potentially revised role of CNC machinists. The literature reviewed in chapter 3 finds that hypermedia-based information systems have a future in manufacturing (Leung, et al., 1995 (part II); Gunasekaran, et al., 1996; Schlick, et al., 1995; Crowder, et al., 2000). Nevertheless, the use of kiosks (Slack & Rowley, 2002) in manufacturing is not extensive. Based upon the findings of this research it is recommended that the use of hypermedia at the shopfloor is researched further. Researchers should focus upon:

- Further research into the configuration and use of kiosks in manufacturing;
- Further research into hypermedia interfaces specifically for CNC machinists.

This research will therefore develop shopfloor information systems that provide effective and efficient support of CNC machinists' work tasks.

Based upon the experiences of this research, it is strongly recommended that researchers pursuing a similar subject carefully consider the appropriateness of particular research methodologies. During this research it was found that despite producing valid findings the selected methodology was unable to control external influences such as quality assurance requirements, and was difficult to manage. By making a distinction between CNC machinist research and hypermedia/kiosk research, it is intended that different research methodologies are employed for each to avoid the issues discussed in section 7.3. It is recommended that CNC machinist research will continue in the field, whilst hypermedia/kiosk research will revert to controlled research environments.

7.6 Conclusions

In conclusion, this research achieves more than just testing the 2 hypotheses. The research community and the sponsor are now better informed of how to continue this research and of methodological considerations.

The key finding of this research is that hypermedia-based information systems are no less effective or efficient than paper-based systems at supporting independent decision-making (Seppälä, et al., 1989; Tuominen, et al., 1989) and cross-boundary communication (Wall, et al., 1990; Sauer, et al., 2000) in production environments with limited divisions of labour (Hirsch-Kreinsen, 1993). This is attributed to information being a supplementary form of support. CNC machinists typically refer to tacit experiential knowledge before reverting to information, if necessary (Kasvi, et al., 1996; Böhle, et al., 1994). Hence the type of media used to present support information is unlikely to greatly impact the overall productivity of processes in current production environments.

Nevertheless, it is found that business benefit can be derived from hypermedia-based systems, due to substantially less administrative costs than paper-based systems (McLean, 1990; Willis, et al., 2002). Provisional cost benefit analysis estimates an annual saving of £50,000 and a 3 year payback on investment.[74] It is therefore arguable that the immediate benefit of electronic information systems is within the technical community and not at the shopfloor.

The research findings therefore enable the sponsor to continue to research shopfloor hypermedia systems, with the knowledge that CNC machinists have accepted the technology and that a wider benefit can be derived. Indeed, Rolls-Royce aim to improve their information infrastructure to provide greater integration across their manufacturing plants. It is therefore not unrealistic to assume that manufacturing engineers at a particular site will eventually be required to work with CNC machinists in other locations (Takahashi & Yana, 2000). Hence, the shopfloor benefits of electronic technical packages and communication channels will be realised as the proximity of support staff changes.

Equally, the need to develop the competence of users in line with the technology (Hyer, et al., 1999) cannot be overstated. As communication

[74] Refer to Appendix D.

channels change via new technologies, CNC machinists and other functions will have to adapt. That is to say that where face-to-face communication is not possible, alternatives such as e-mail will be essential. Hence, this research has only begun to unearth the potential of shopfloor hypermedia systems, and the potential of CNC machinists.

As business endeavours to continually improve operations, new technologies such as hypermedia are sought. Hence, employees such as CNC machinists must therefore continually increase their skills (Jackson & Wall, 1991; Seppälä, et al., 1989; Tuominen, et al., 1989; Mårtensson and Stahre, 1992). It is the responsibility of the research community to identify and develop those skills in parallel with new technology development to ensure that business benefit is achieved and knowledge is advanced.

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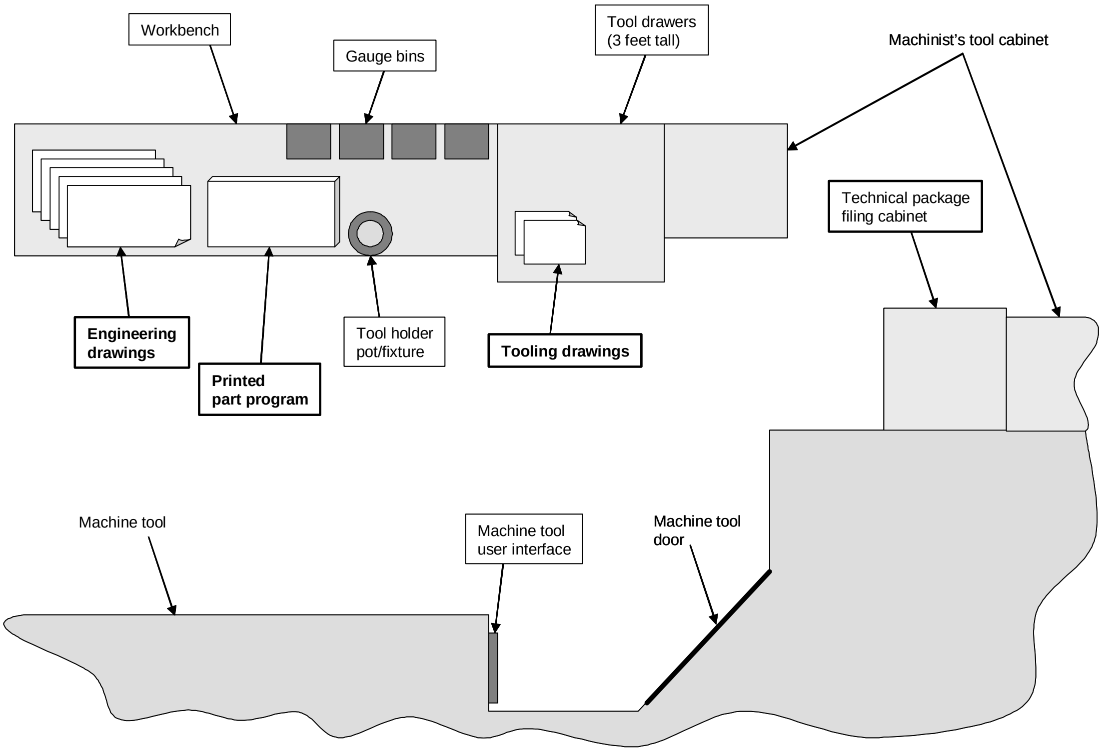
Appendix A – Formative evaluation data

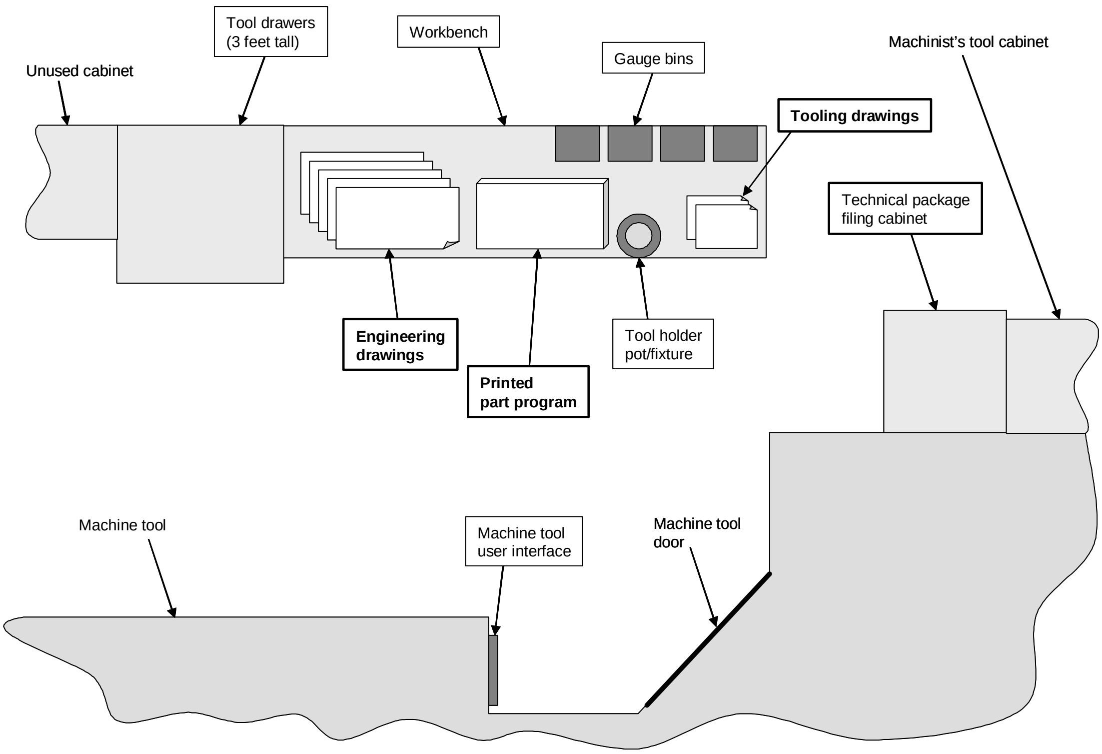
To supplement the formative evaluation results provided in the main body of the thesis, the follow information are provided:

- A plan view of the workstations at the 2 machine tools of the evaluation research setting, to represent how the studied CNC machinists layout the existing paper-based technical package ready for use.
- The $IDEF_0$ model produced from task analyses for reference.
- Stakeholder analysis results for reference.

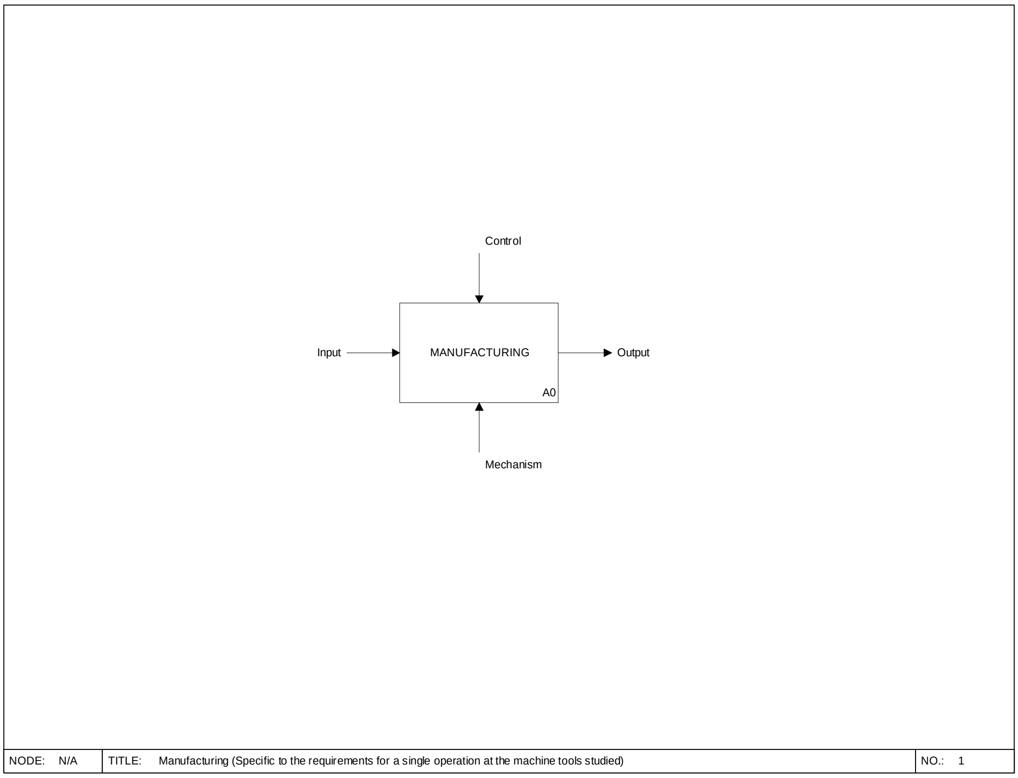
Machine tool 1 workstation – plan view (not to scale)

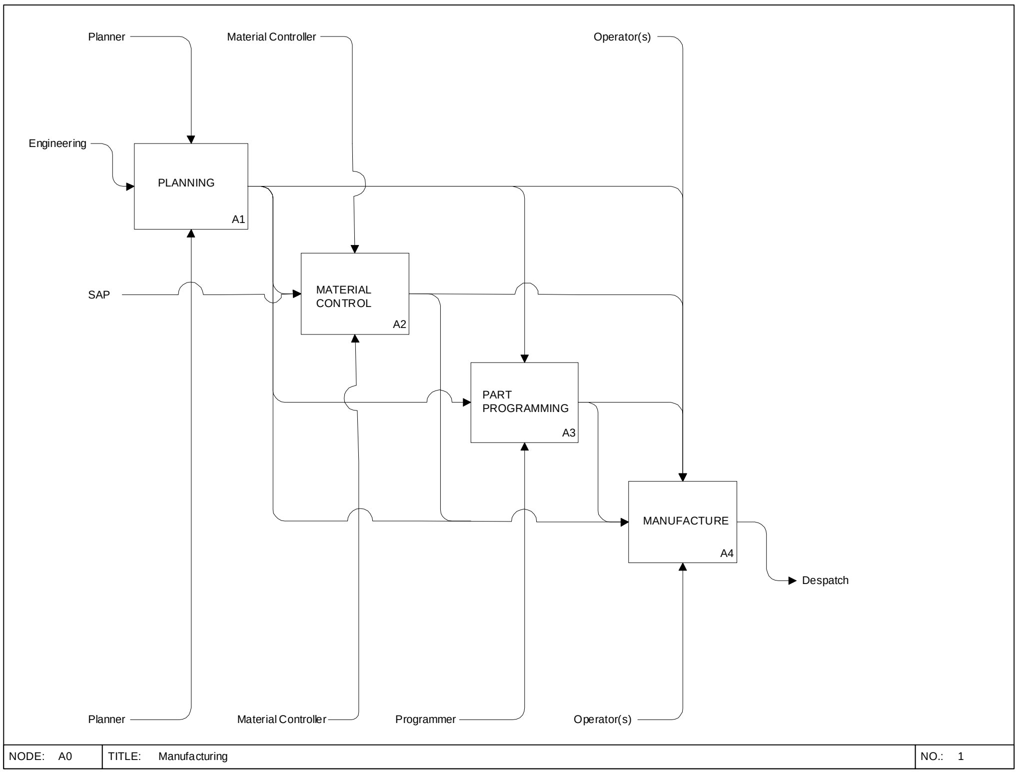


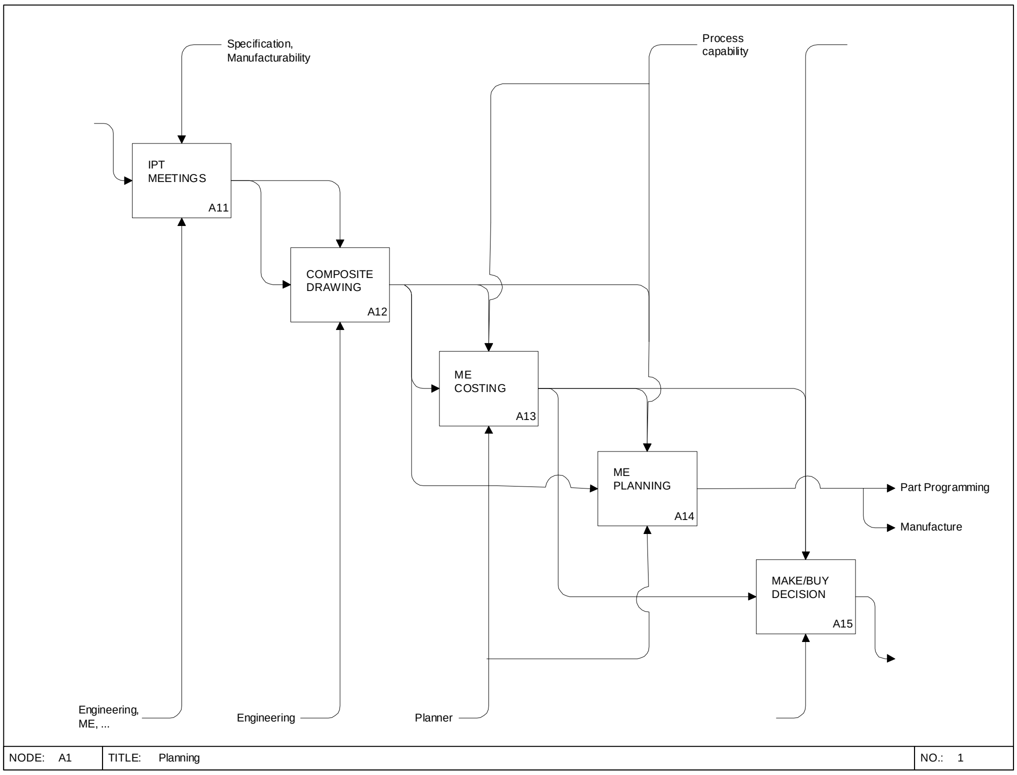
Machine tool 2 workstation – plan view (not to scale)



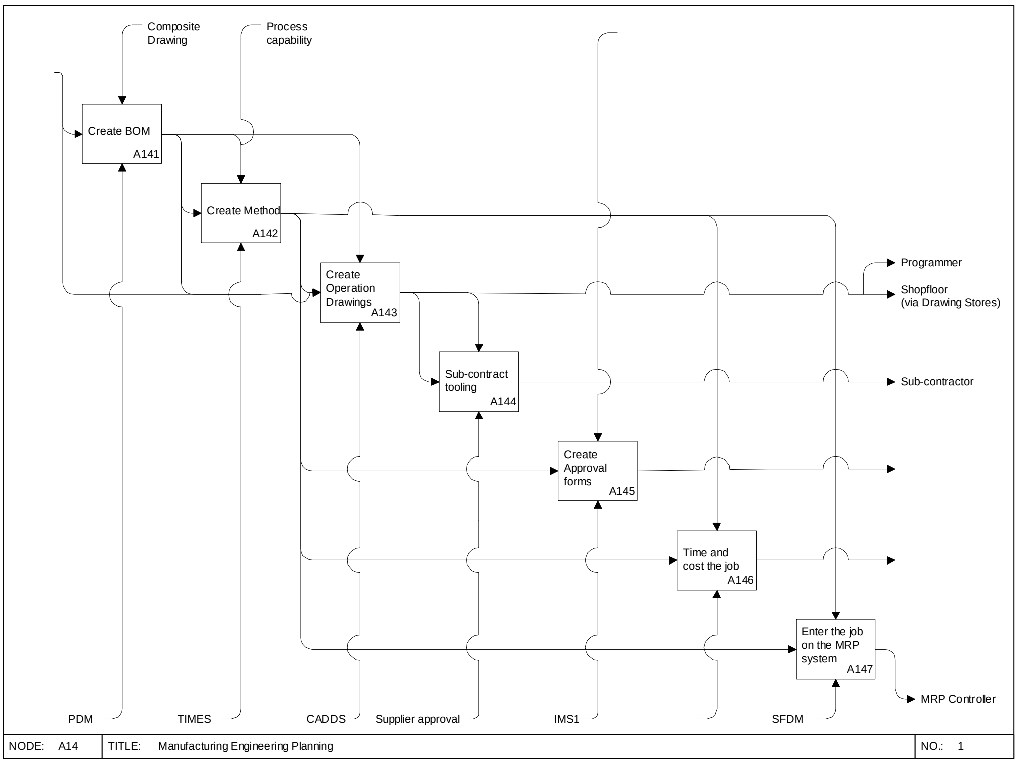
Workstation layouts at the evaluation research setting


Control
Input
MANUFACTURING
A0
Output
Mechanism
NODE: N/A
TITLE: Manufacturing (Specific to the requirements for a single operation at the machine tools studied)
NO.: 1

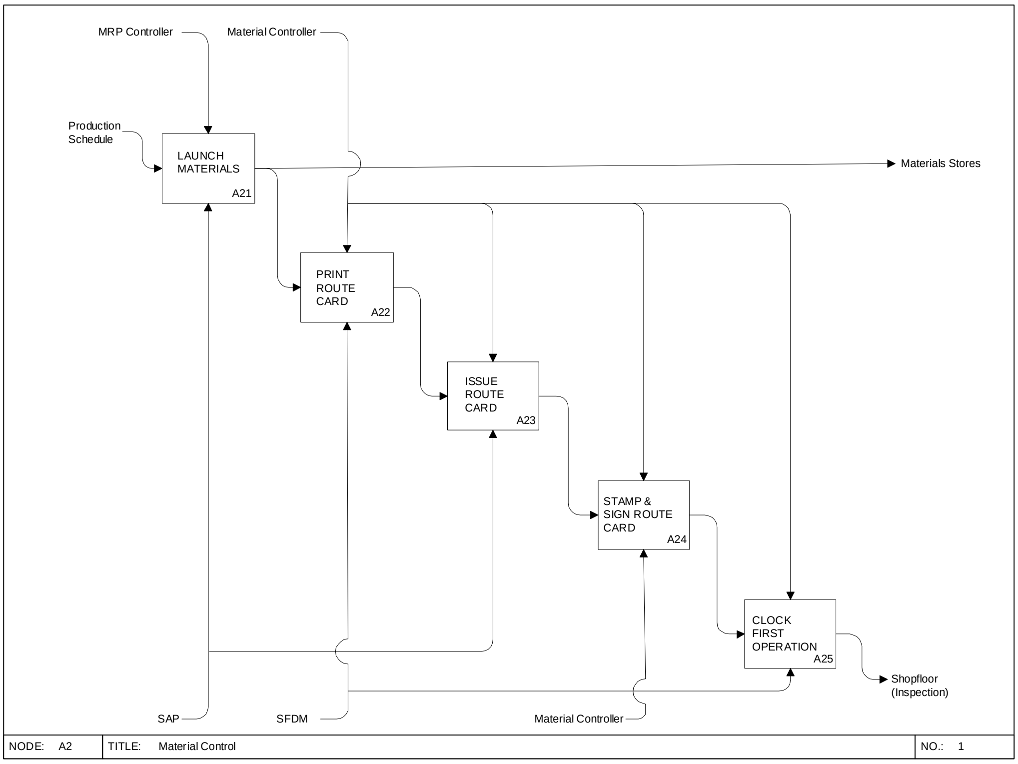

Planner
Material Controller
Operator(s)
Engineering
PLANNING
A1
SAP
MATERIAL CONTROL
A2
PART PROGRAMMING
A3
MANUFACTURE
A4
Despatch
Planner
Material Controller
Programmer
Operator(s)
NODE: A0
TITLE: Manufacturing
NO.: 1

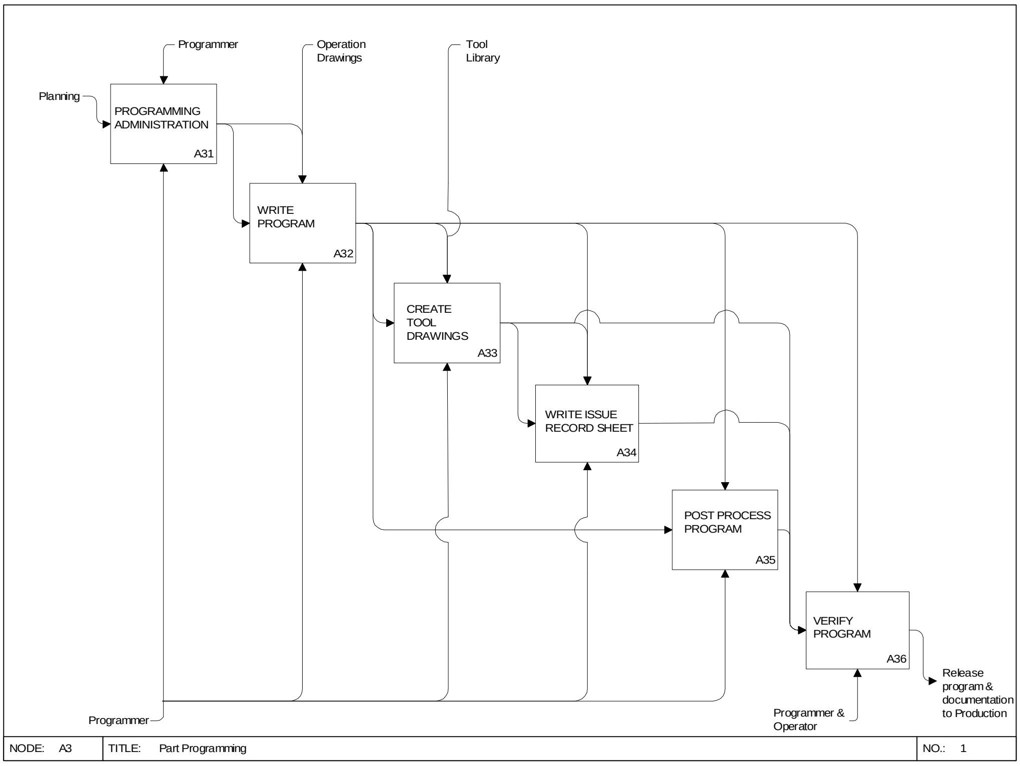


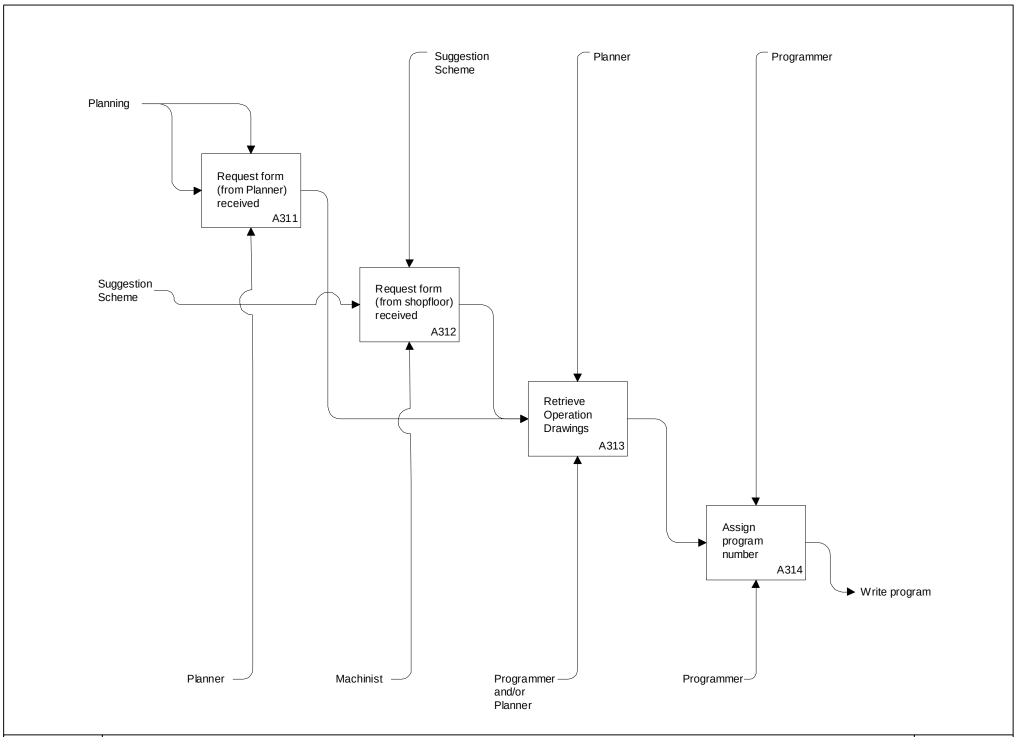
Specification, Manufacturability
Process capability
IPT MEETINGS
A11
COMPOSITE DRAWING
A12
ME COSTING
A13
ME PLANNING
A14
MAKE/BUY DECISION
A15
Part Programming
Manufacture
Engineering, ME, ...
Engineering
Planner
NODE: A1
TITLE: Planning
NO.: 1



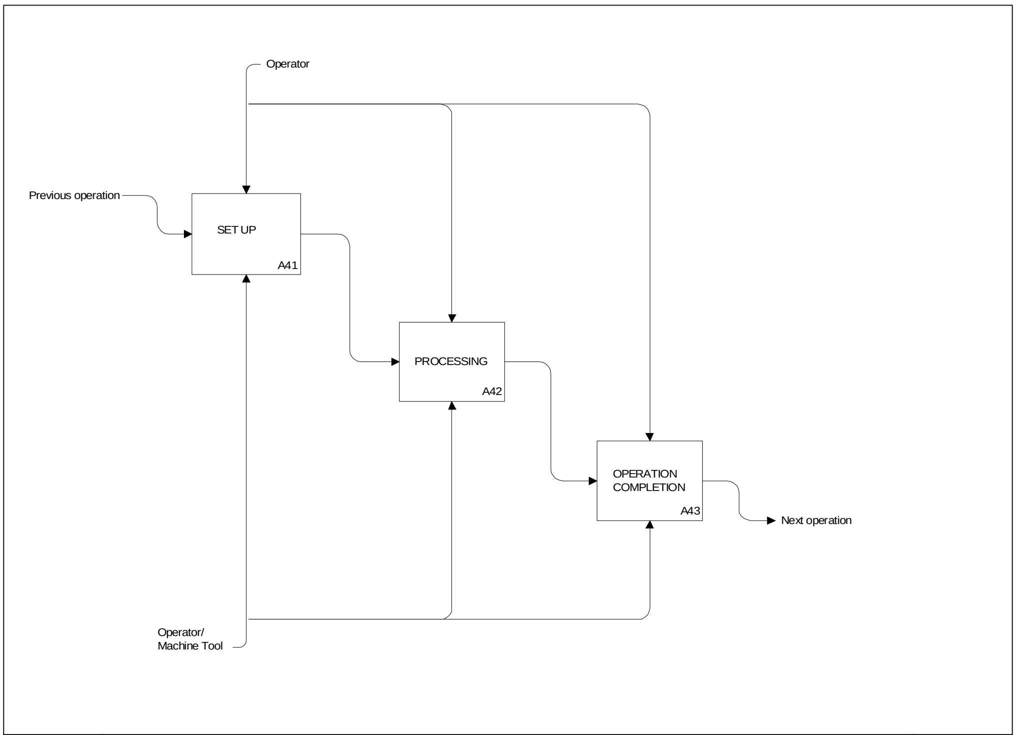
Composite Drawing
Process capability
Create BOM
A141
Create Method
A142
Create Operation Drawings
A143
Sub-contract tooling
A144
Create Approval forms
A145
Time and cost the job
A146
Enter the job on the MRP system
A147
Programmer
Shopfloor (via Drawing Stores)
Sub-contractor
MRP Controller
PDM
TIMES
CADDS
Supplier approval
IMS1
SFDM
NODE: A14
TITLE: Manufacturing Engineering Planning
NO.: 1


MRP Controller
Material Controller
Production Schedule
LAUNCH MATERIALS
A21
Materials Stores
PRINT ROUTE CARD
A22
ISSUE ROUTE CARD
A23
STAMP & SIGN ROUTE CARD
A24
CLOCK FIRST OPERATION
A25
Shopfloor (Inspection)
SAP
SFDM
Material Controller
NODE: A2
TITLE: Material Control
NO.: 1


Programmer
Operation Drawings
Tool Library
Planning
PROGRAMMING ADMINISTRATION
A31
WRITE PROGRAM
A32
CREATE TOOL DRAWINGS
A33
WRITE ISSUE RECORD SHEET
A34
POST PROCESS PROGRAM
A35
VERIFY PROGRAM
A36
Release program & documentation to Production
Programmer
Programmer & Operator
NODE: A3
TITLE: Part Programming
NO.: 1



NODE: A31	TITLE: Programming Administration	NO.: 1



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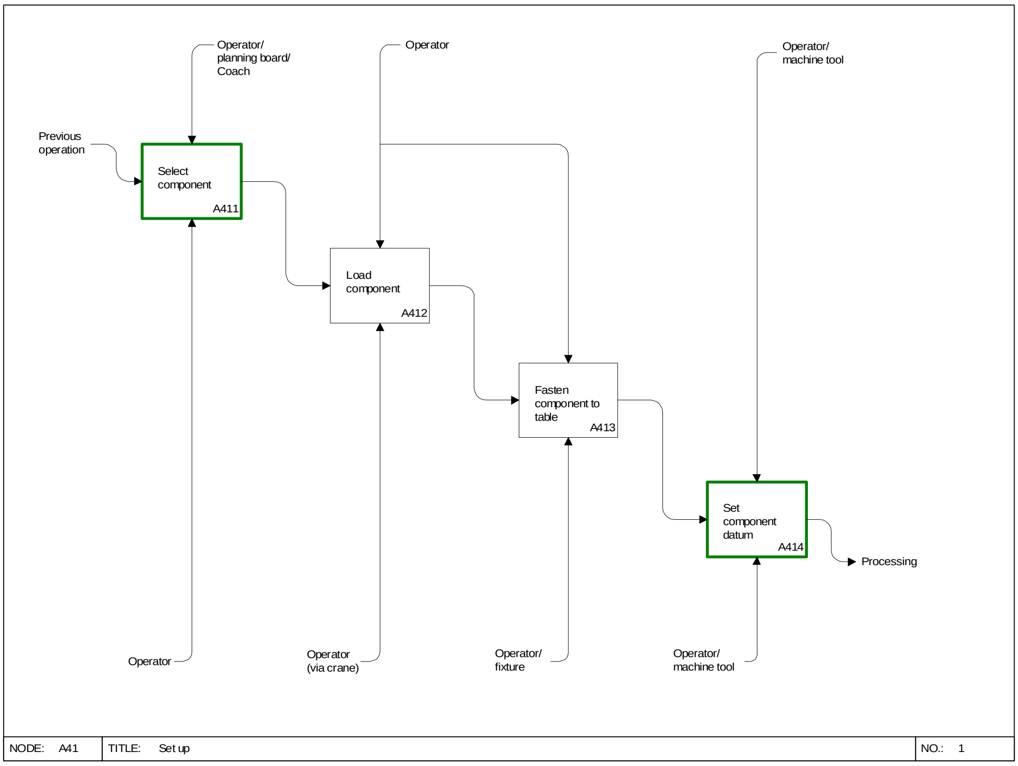

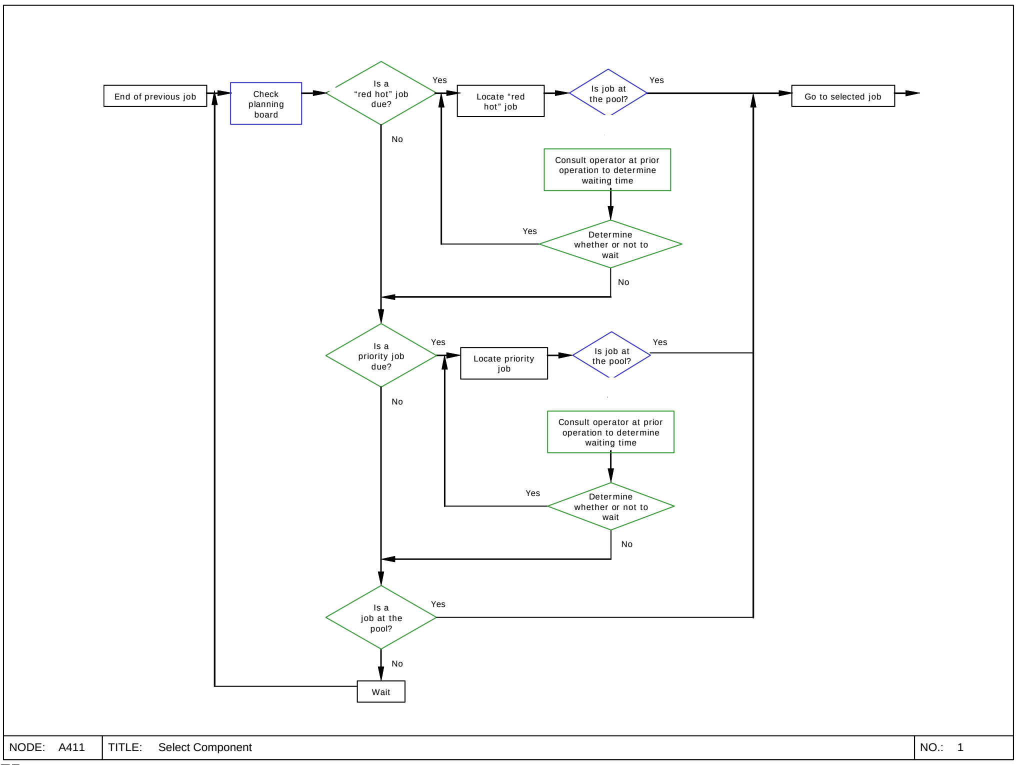

75

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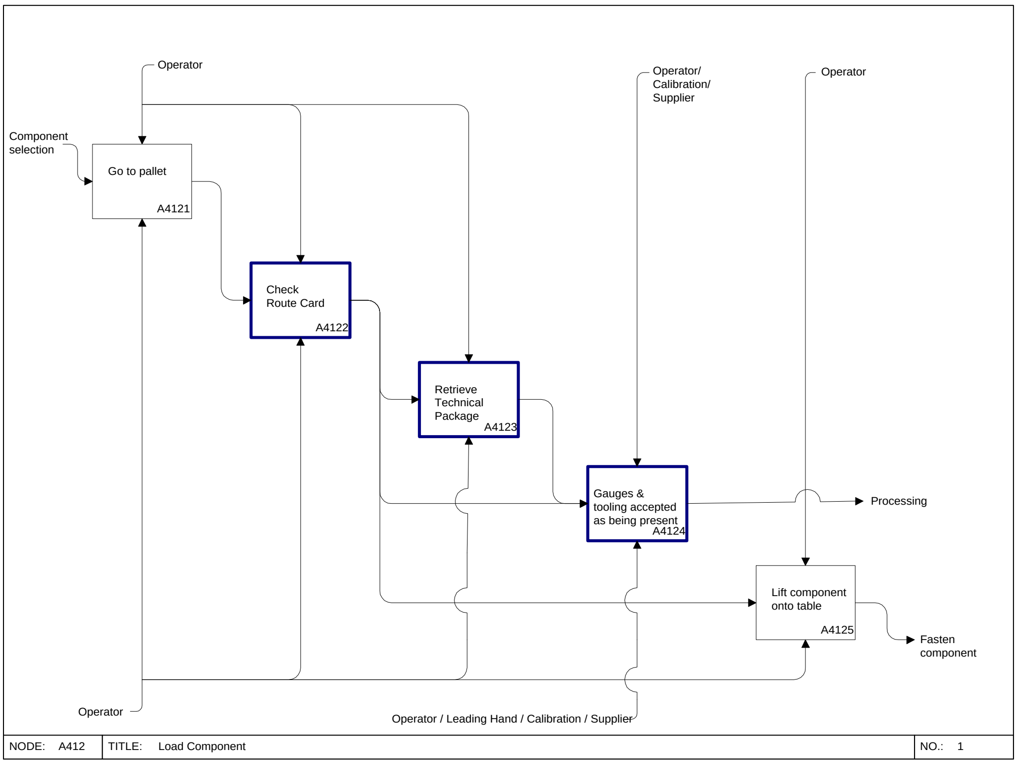
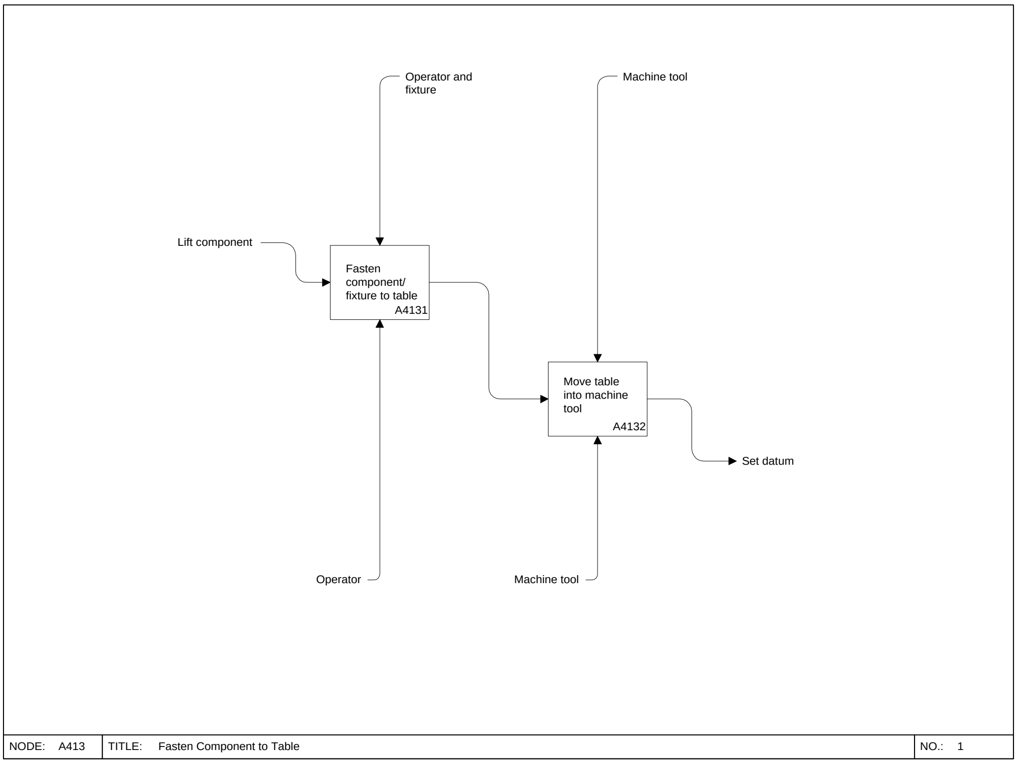
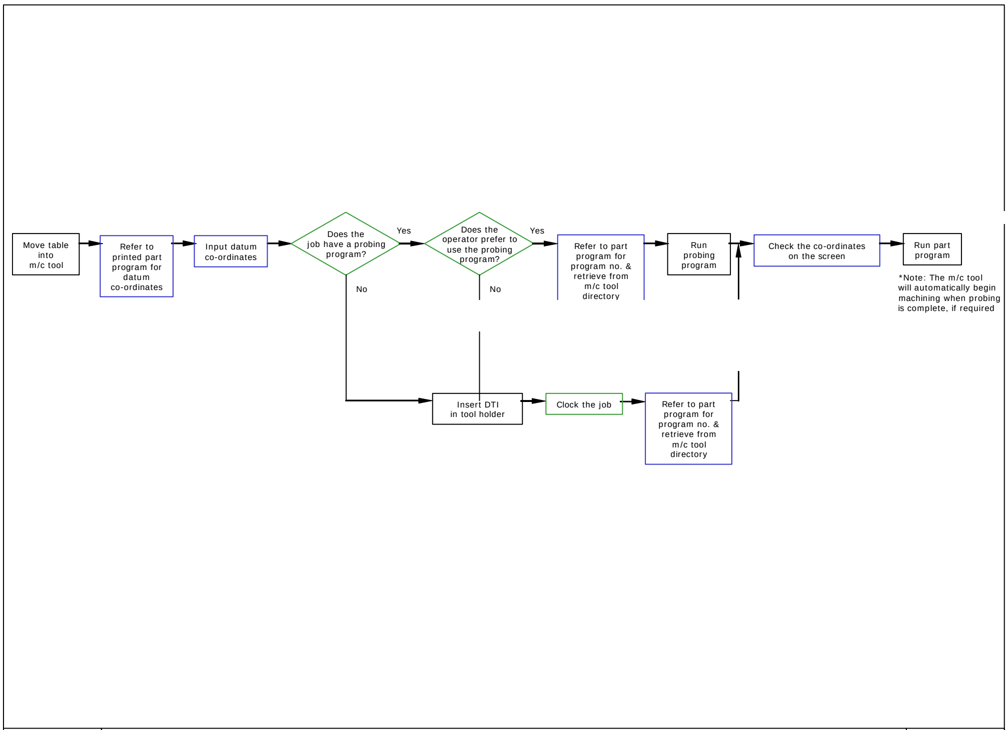
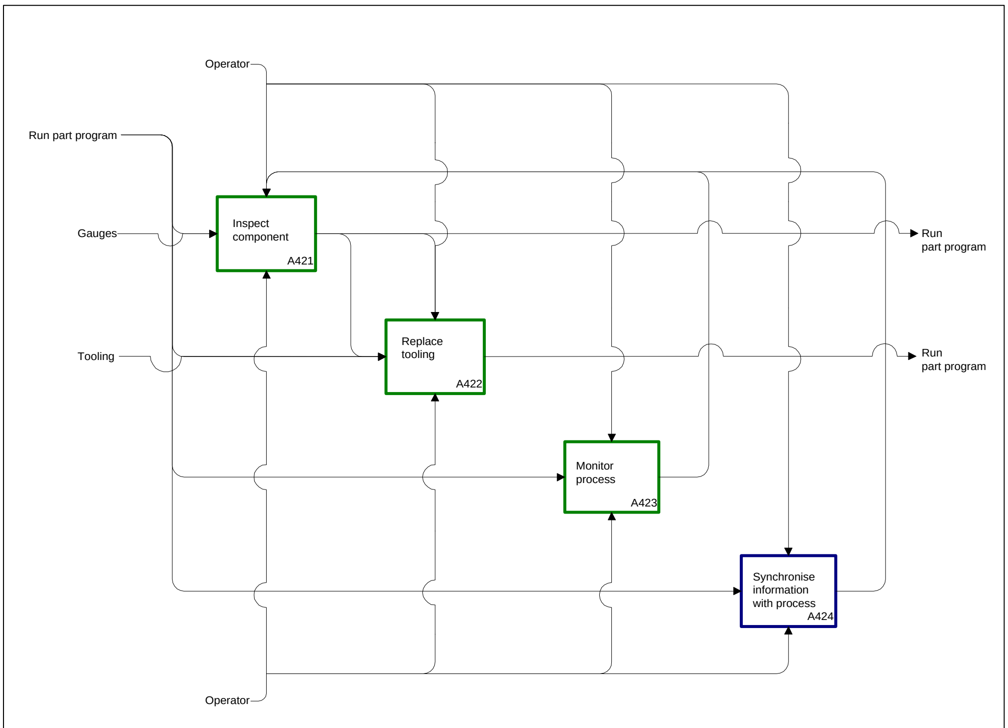
75 Key: Blue box = CNC machinist information-supported tasks; Green box = CNC machinist knowledge-supported tasks.


Operator
Operator/
Calibration/
Supplier
Operator
Component
selection
Go to pallet
A4121
Check
Route Card
A4122
Retrieve
Technical
Package
A4123
Gauges &
tooling accepted
as being present
A4124
Processing
Lift component
onto table
A4125
Fasten
component
Operator
Operator / Leading Hand / Calibration / Supplier
NODE: A412
TITLE: Load Component
NO.: 1


Operator and
fixture
Machine tool
Lift component
Fasten
component/
fixture to table
A4131
Move table
into machine
tool
A4132
Set datum
Operator
Machine tool
NODE: A413
TITLE: Fasten Component to Table
NO.: 1

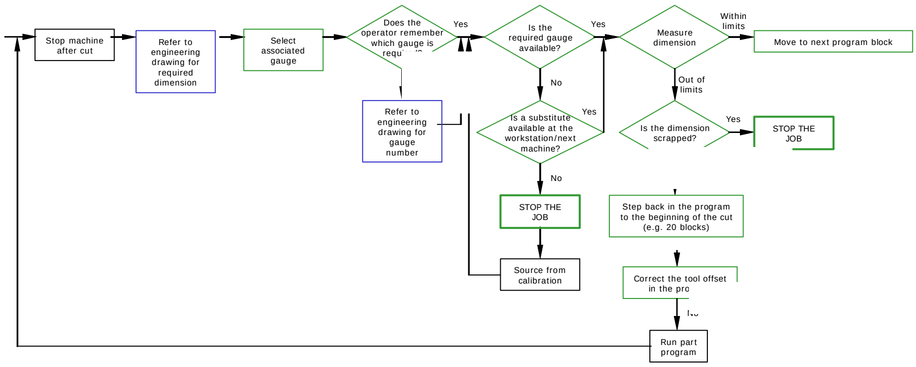


NODE: A414 | TITLE: Set Component Datum | NO.: 1

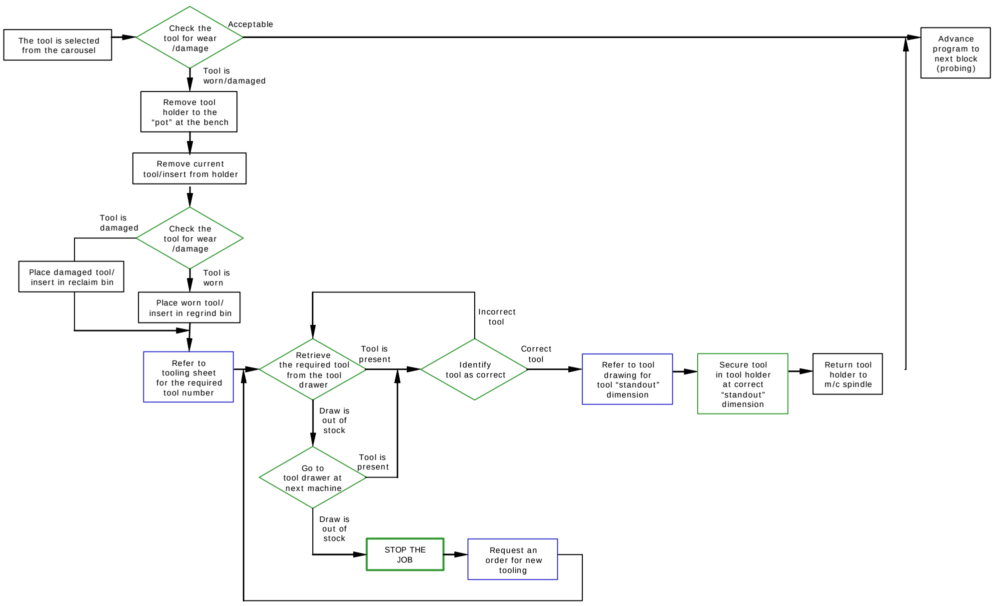


NODE: A42 | TITLE: Processing | NO.: 1

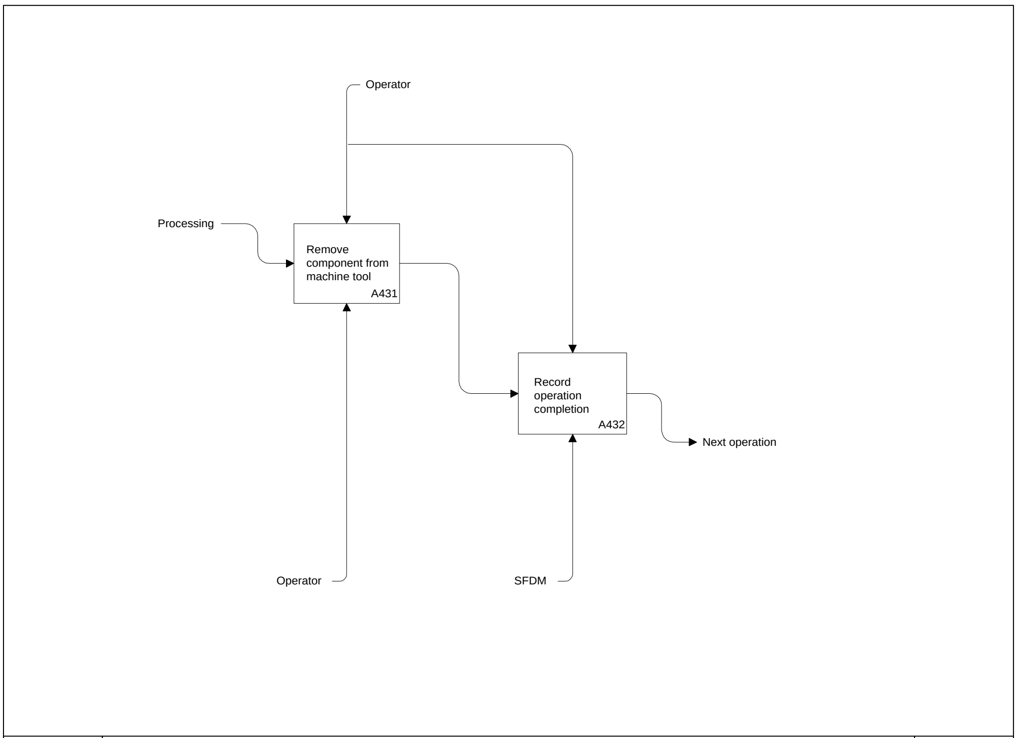
PRECONDITION FOR THE LOOP
If the cut is a series of drilled holes the operator will stop the machine after the first hole to inspect it. If accepted, the remaining holes will then be drilled and inspected (via random sampling) when all have been drilled. All other machining operations are discretionary.



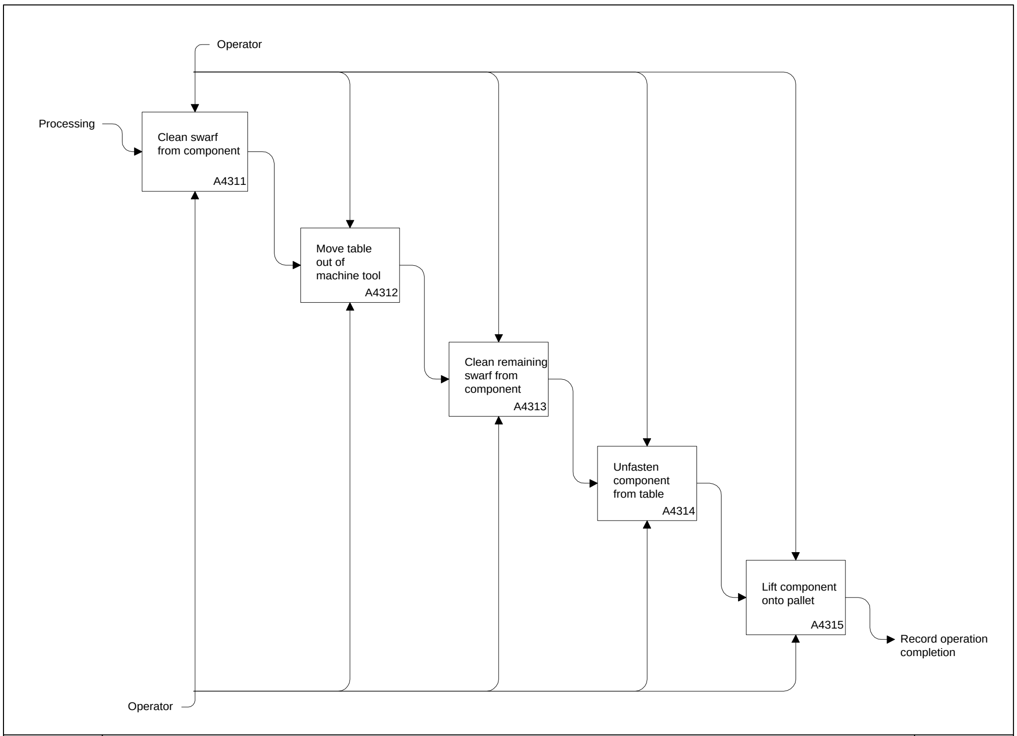
NODE: A421 | TITLE: Inspect Component | NO.: 1



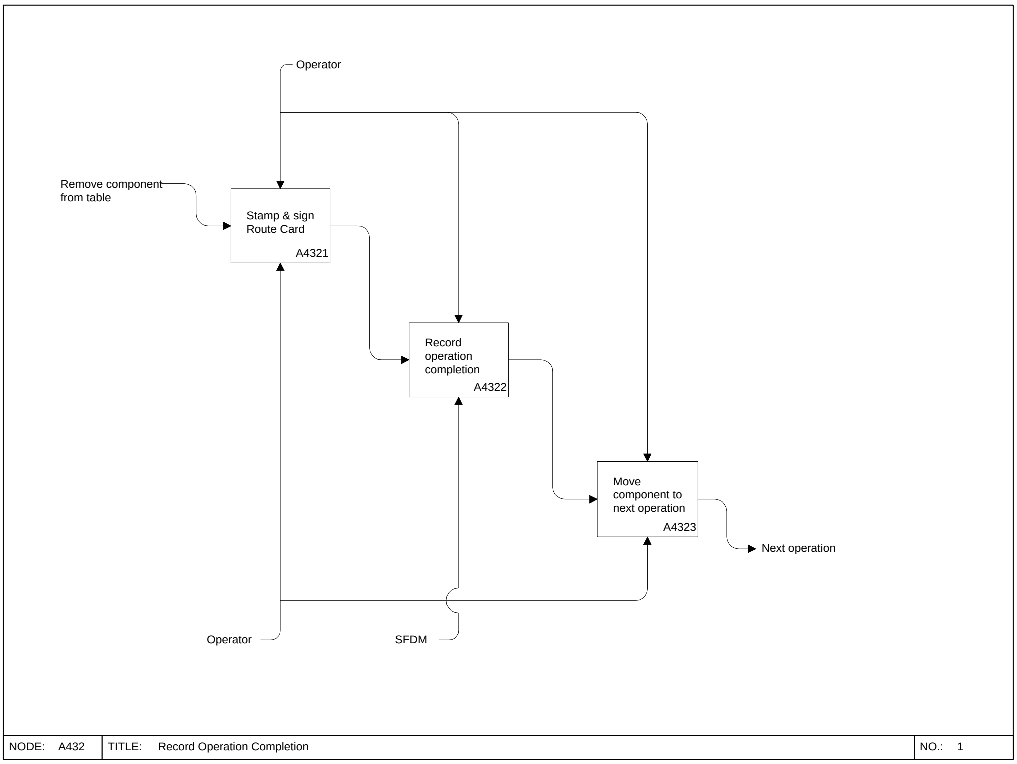
NODE: A422 | TITLE: Replace Tooling | NO.: 1



NODE: A43 | TITLE: Operation Completion | NO.: 1



NODE: A431 | TITLE: Remove Component from Machine Tool | NO.: 1



IDEF$_0$ model of task analyses

	Stakeholders	Personal responsibility	Impact on operator	Process impact	Relative priorities of interest
Primary stakeholders	CNC machinist	Accountable for local product delivery	+/-	+	=1st
		Accountable for local product quality	+/-	+	
		Accountable for local productivity	+/-	+	
		Accountable for Technical package storage	-	-	
		Accountable for cutting tool stocks	+	+	
		Accountable for gauge storage	-	-	
		Accountable for machine tool calibration	+	+	
		Accountable for preventive maintenance and workstation order	-	+	
		Each operator is different	+/-	-	
	Shiftmate	Previous shift reports all task issues from before	+	+	=1st
		Next shift receive all task issues from this shift	+	+	
		Operator at the next machine is available for manual assistance	+	+	
		Operator at the next machine is available for decision support	+	+	
		Operator at the next machine is available for general discussions	+	+/-	
	Coach	Operators' 1st line manager	+/-	+/-	2nd
		Sanctions annual leave, etc.	+/-	+	
		Accountable for keeping to schedule	+/-	+	

		Discusses the schedule with operators	+	+/-	
		Closely monitors progress	-	+	
		Can and will reschedule as required	-	+	
	Cell leader	Accountable for delivery targets	-	+	3rd
		Manages delivery through coaches	-	+	
		Accountable for performance improvement	-	+	
		Manages improvement through cost reduction	-	+	
		Encourages traceability & accountability	-	+	
		Accountable for resource allocation	-	+	
		Has infrequent contact with operators	+/-	+	
Secondary stakeholders	ME Programmer	Deliver program	+	-	4th
		Deliver tool drawings	+	-	
		Control program changes	+/-	+	
		Control cutting tool changes	+/-	+	
		Consulted on program issues	+/-	+/-	
		Consulted on cutting tool issues	+/-	+/-	
		Consulted on tool replacement issues	+/-	+/-	
		Cyclical workload	-	-	
		Continually trialling new programs/tools	+/-	-	
	ME Planner	Deliver engineering drawings	+	-	6th
		Control process changes	+/-	+	
		Consulted on component issues	+/-	+/-	
		Consulted on fixture	+/-	+/-	

		issues			
		Consulted on concessions	+/-	+/-	
		Cyclical workload	-	-	
		Little or no contact	+	-	
	Inspector	Accountable for product quality	+	+	7th
		Little or no contact/input	+	+	
	Leading hand	Accountable for cutting tool orders	+	+	5th
		Accountable for gauge calibration	+	+	
		Constant contact with the whole shop (the grapevine)	+	+/-	
		Is available for general discussions	+	-	
		Likes to be involved and in the know	+	+/-	
External stakeholders	Tool rep	Restocks cutting tools at the workstation	+	+	9th
		Discusses tool performance	+	+/-	
		Tries to sell new products	+	-	
		Tries to understand requirements	+	+/-	
	Tool room	Accountable for fixtures	+	+	8th
		Little or no contact/input	+/-	+	
	Maintenance	Contacted for machine tool maintenance	+/-	+/-	10th
		Contacted for workstation maintenance	+/-	-	
		Little or no contact/input	+/-	+	

Stakeholder analysis table

Appendix B –

Prototype hypermedia system development

Introduction

To test the research hypotheses, a prototype information system was developed to provide an electronic technical package and an electronic communication tool. A kiosk system was selected to provide security, usability and robustness within the hardware and software. The selected hardware comprised a lockable cabinet with a specially adapted touch screen interface, which housed a standard desktop PC (refer to the photograph below).

Prototype kiosk hardware

The software comprised a 'public browser interface'. This is an off-the-shelf software designed for public-use kiosks. It prevents users from accessing desktop functions other than what is essential, thereby providing security and robustness. Usability is enabled by the hypermedia pages viewed through the browser.

System development

An appropriate information systems development methodology was required to provide a structured approach to deliver the required kiosk functionality and usability, to therefore ensure that users were not deterred from using it as result of insufficient kiosk capability. User input was also a requirement. The selected information systems development methodology was the soft systems methodology (Checkland & Scholes, 1992). This user-centred problem-solving approach facilitated user input and iteration until the prototype provided the functionality required by the users.

In practice, the kiosk was installed at the experimental group's workstation at the beginning of the development period to allow them to familiarise themselves with its functions. The preliminary kiosk content and file structure were developed from the task and stakeholder analyses. This prompted discussions of system requirements with users (e.g. repositioned buttons), which were recorded via fieldnotes and later transcribed using rich pictures, root definitions and conceptual models to define specific requirements for development. The kiosk content was then developed and installed for further discussion. This process was iterated 4 times before the kiosk was implemented for productive use. Users confirmed the kiosk's effective and efficient navigation via a usability assessment prior to implementation.

During the summative evaluation period, the kiosk content required updating as information was up-issued. Further developments were also necessary. The two key improvements were a change to the program interface, and a new communication tool. It was found that the drawing interface (a PDF viewer) provided sufficient usability; whilst the program interface (HTML) was constrained by the need to use a horizontal scroll bar. The file format for the programs was therefore changed to match the drawings.

The second improvement was the communication tool. It was found that the tool implemented first (a web-based discussion forum) was not simple enough to use. The concept of threaded discussions, etc. was an over-complication to these relatively new computer users. They therefore specified the requirements for a simple note writing tool that displayed records via a list without a search facility.

Kiosk screen images are provided in figures 5.3 and 5.8.

System issues

Section 7.2 discusses project constraints. Some of which are attributed to the kiosk. However, it is important to note that the hardware configuration was developmental. The provision of secure and robust hardware was reliant upon a continuous power supply, stable software and constant technical support. These three factors combined to limit kiosk usage, thereby impacting the research.

Catastrophic failure of the power supply was a risk that had not been considered. However, extreme weather conditions caused a temporary failure. This combined with a long period without technical support to limit the availability of the kiosk. The kiosk was locked for security and only accessible by the researcher. If, however, the kiosk hardware would have been accessible to users, they could have reset the system to minimise the impact of this issue.

Software stability was also an issue. As discussed, the software is designed to provide a ‘tamper-proof’ and therefore robust interface. Nevertheless, the software became increasingly unstable throughout the research. This is evidenced by the kiosk usage data. Consultation with the software vendor did not produce a solution. Hence, users found that the kiosk would reboot during productive use, so therefore typically reverted using to paper-based information. Software selection is therefore a key consideration for future researchers and developers.

Recommendations

The development and testing of the kiosk constrained the research project. The development period utilised a substantial proportion of the available resource, whilst the evaluation period was constrained by the issues discussed. It is therefore evident that kiosk development and support would have been better managed as a separate project. However, resource constraints dictated that the kiosk development and the research were run together.

It is recommended that future researchers consider the combination of kiosk and research issues before undertaking similar projects. The recommendations in section 7.5.2 state that a laboratory-based experimental methodology would provide greater control of research variables. This approach would also control project issues such as technical support. Hence, from the experiences of this project, the development of information systems should be conducted in better controlled environments to manage risks and issues before embarking on research and implementation.

Appendix C – Summative evaluation data

To supplement the summative evaluation results provided in the main body of the thesis, the follow information are provided:

- A blank diary page to show cross-boundary communications data collection.
- Sorted and filtered fieldnote summaries.

Today's date: ___________ **The shift you worked** (circle one)**:** Days / Lates / Nights

1. COMMUNICATION WHILST THE MACHINE TOOL WAS RUNNING

	Who did you communicate with and how? (enter an F, K or B in ?1 boxes)										What did you discuss? (enter a tick in ?1 boxes)										Where?		
Approx time of day	shift mate	coach	programmer	planner	cell leader	inspector	Pete B.	tool rep.	tool room	maintenance	shift handover	scheduling issue	asked for manual assistance	component issue	m/c tool issue	program issue	tool cutting issue	tool replacement issue	gauge issue	other	at the m/c	away from the m/c	Duration (minutes)

2. COMMUNICATION WHILST THE MACHINE WAS NOT RUNNING

	Who did you communicate with and how? (enter an F, K or B in ?1 boxes)										What did you discuss? (enter a tick in ?1 boxes)										Where?		
Approx time of day	shift mate	coach	programmer	planner	cell leader	inspector	Pete B.	tool rep.	tool room	maintenance	shift handover	scheduling issue	asked for manual assistance	component issue	m/c tool issue	program issue	tool cutting issue	tool replacement issue	gauge issue	other	at the m/c	away from the m/c	Duration (minutes)

Key: F = Face to face; K = Kiosk; B = Both

Participant diary page

ID	SUBJECT	STAKEHOLDER	DATE	DATA SOURCE	RELEVANT RESEARCH PHASE	RELEVANT ANALYSIS METHOD
4	INITIAL REACTION TO THE INTRODUCTION OF ELECTRONIC IS WAS APPREHENSIVE. BY FOCUSING ON PROVIDING CONTENT, BUY-IN SHOULD BE ACHIEVED	CNC MACHINIST	23/01/ 2002	JOURNAL	FORMATIVE	GENERAL
6	STANDARDISATION AND ISSUE CONTROL OF INFORMATION ARE THE MOST IMPORTANT ISSUES TO THIS DEPARTMENT. FOCUS ON THIS!	MFG ENG	23/01/ 2002	JOURNAL	FORMATIVE	GENERAL
1	FEW BARRIERS EXIST BETWEEN M/CISTS & ME. INFORMAL DISCUSSIONS ARE COMMON. PROACTIVE AND EMPOWERED TEAM ENVIRONMENT.	CNC MACHINIST	23/01/ 2002	JOURNAL	FORMATIVE	SA
2	DIFFERENT OPERATORS FOCUS ON DIFFERENT OBJECTIVES OF THE WORK. SOME ARE SPECIALISTS, WHILST OTHERS ARE GENERALISTS.	CNC MACHINIST	23/01/ 2002	JOURNAL	FORMATIVE	TA
3	LEADTIMES ARE HIGHLY VARIABLE. STANDARD JOB TIMES ARE IN EXCESS OF 40 HOURS, BUT ARE NOT RIGIDLY APPLIED.	CNC MACHINIST	23/01/ 2002	JOURNAL	FORMATIVE	TA
115	SYSTEMS USED IN THE DEPT: SFDM - JOB CARDS LINK TO MRP; DNC - V.RECENT ADDITION; SOURCERER - DIRECT ON-LINE TOOLING ACQUISITION	N/A	24/01/ 2002	FIELDNOTES	FORMATIVE	TA
7	RELATED SYSTEMS ARE BEING CONSIDERED AT A STRATEGIC & DEPARTMENTAL LEVEL (E.G. DNC, TOOL MANAGEMENT & CAPP) THAT COULD OFFER POTENTIAL SOLUTIONS. THIS SHOULD BE BOURN IN MIND.	MFG ENG	24/01/ 2002	JOURNAL	FORMATIVE	GENERAL
8	KAIZEN IS PRACTISED AT A SHOPFLOOR LEVEL AND IS ORGANISED THROUGH A SPECIALIST BY THE OPERATORS. KAIZEN EVENTS ARE COMMON ACROSS THE DEPARTMENT. THIS MAYBE USEFUL.	CNC MACHINIST	24/01/ 2002	JOURNAL	FORMATIVE	GENERAL
11	JOBS ARE LONG WITH LITTLE OPERATOR INPUT	CNC MACHINIST	30/01/ 2002	JOURNAL	FORMATIVE	TA
12	PART PROGRAM ISSUE	CNC	30/01/	JOURNAL	FORMATIVE	SA

	CONTROL IS A PROBLEM: THERE ARE 2 CODES FOR EACH PROGRAM, SO OPERATORS HAVE NO DEFINITIVE WAY OF ENSURING IT IS AT CORRECT ISSUE. THE QUALITY CONTROL 'BURDEN' IS ON THE OPERATOR, ALTHOUGH ME CONSIDER THEMSELVES IN CONTROL OF THIS.	MACHINIST	2002			
13	5 FOLDERS FOR 1 JOB!!! 1. JOB CARD THAT STAYS WITH THE JOB THROUGH THE SYSTEM. 2. PRINTED PROGRAM. 3. A TOOLING LIST WITH TOOL DRAWINGS. 4. AN ISSUE LIST TO SHOW WHAT ISSUE EVERYTHING SHOULD BE AT. ALL IS STORED IN A FILING CABINET.	CNC MACHINIST	30/01/2002	JOURNAL	FORMATIVE	TA
14	THE FILING CABINETS AT THE STUDIED M/CS WERE SOURCED BY THE OPERATORS. NO OTHER M/C HAS A CABINET. ALSO, THE FILING SYSTEM IS NOT A SYSTEM. IT IS DISORGANISED AND PRONE TO ERROR (IMAGINE WHAT IT MUST BE LIKE AT OTHER MACHINES!?!).	CNC MACHINIST	30/01/2002	JOURNAL	FORMATIVE	TA
15	OPERATORS ARE AWARE OF ISSUES IN THE SYSTEM/PROCESS BUT INHERENTLY DO NOT RAISE THEM FORMALLY. HOWEVER, THEY ARE WILLING TO DISCUSS SOLUTIONS THEY HAVE THOUGHT THROUGH TOGETHER. CAN THIS KNOWLEDGE BE HARNESSED TO INITIATE IMPROVEMENT?	CNC MACHINIST	30/01/2002	JOURNAL	FORMATIVE	TA
16	INTERVIEW WITH MATERIAL CONTROLLER (TAPED AND TRANSCRIBED). THE MATL CONTROLLER HAS A SIMILAR ROLE TO THE COACH IN TERMS OF PROGRESS CHASING. HENCE, HE WILL BE REFERRED TO GENERICALLY AS A COACH.	COACH	30/01/2002	JOURNAL	FORMATIVE	TA
17	1ST OPERATOR TASK ANALYSIS INTERVIEW. ONCE TRANSRIBED, THE RESULTANT MODEL CAN BE CHECKED WITH THE OPERATORS PRIOR TO THE NEXT INTERVIEW. THIS WILL BE ITERATED UNTIL THE OPERATORS ARE SATISFIED THAT IT IS	CNC MACHINIST	30/01/2002	JOURNAL	FORMATIVE	TA

	CORRECT.					
116	PRELIM TA SHOWS THAT INFORMATION IS GENERALLY PASSED ON AT SHIFT HANDOVER. THERE IS A NEED TO UNDERSTAND THIS	CNC MACHINIST	30/01/ 2002	FIELDNOTES	FORMATIVE	TA
18	PRESENTATION OF PRELIMINARY TASK MODEL TO OPERATOR. HE EMPHASISED THE NEED FOR SKILL (LISTENING & WATCHING FOR PROBLEMS). SKILL = FLEXIBILITY & ADAPTABILITY.	CNC MACHINIST	31/01/ 2002	JOURNAL	FORMATIVE	TA
117	DATUMS ARE SET AT THE START OF A JOB USING THE PROBING PROGRAM, A CLOCK (DTI) OR BOTH	CNC MACHINIST	31/01/ 2002	FIELDNOTES	FORMATIVE	TA
118	THE TECHNICAL PACKAGE CONSISTS OF: ENG DRGS, TOOLING DRGS/SHEETS, ROUTE/JOB CARD, PROGRAM PRINT OUT	CNC MACHINIST	31/01/ 2002	FIELDNOTES	FORMATIVE	TA
119	AT THE BEGINNING OF A JOB, OPERATORS SHOULD CHECK THEY HAVE ALL NECESSARY GAUGES	CNC MACHINIST	31/01/ 2002	FIELDNOTES	FORMATIVE	TA
120	THE TOOL CHANGES OBSERVED ARE MANUAL. THE AUTOMATED TOOL CHANGE IS STOPPED BY THE OPERATOR BEFORE IT BEGINS CUTTING SO HE CAN CHECK FOR WEAR, ETC. - "STEPPING THROUGH THE PROGRAM" - A KNOWLEDGE-BASED SAFEGUARD = >QUALITY BUT <PRODUCTIVITY	CNC MACHINIST	31/01/ 2002	FIELDNOTES	FORMATIVE	TA
121	SOME OPERATOR WASH DOWN THE JOB WITH COOLANT WHEN FINISHED TO REMOVE SWARF	CNC MACHINIST	31/01/ 2002	FIELDNOTES	FORMATIVE	TA
122	THE JOB IS TRIGGERED BY THE JOB ARRIVING AT THE QUEUE. THE OPERATOR SELECTS THE JOB AT THE FRONT OF THE QUEUE OR THE JOB WITH SPECIAL INSTRUCTIONS. ONLY A COACH CAN OVERRIDE THIS	CNC MACHINIST	31/01/ 2002	FIELDNOTES	FORMATIVE	TA
19	WIDER OPERATOR RESPONSIBILITIES: ENSURE TOOL AVAILABILITY, MONITOR SCHEDULE AND JOB QUEUE, ENSURE NEXT SHIFT HAS WORK	CNC MACHINIST	06/02/ 2002	JOURNAL	FORMATIVE	SA
20	TOOL REP REPLENISHES THE TOOL STOCK IN THE DRAWERS AT THE M/C ONCE A WEEK. NO STOCK OUT, BUT RR ONLY PAY FOR WHAT IS USED	TOOL REP	06/02/ 2002	JOURNAL	FORMATIVE	TA

21	"YOU CAN'T WRITE DOWN EVERYTHING ABOUT WHAT A MACHINIST DOES!" HENCE, THE NEED FOR THE SKILLED MAN	CNC MACHINIST	06/02/2002	JOURNAL	FORMATIVE	TA
22	BASIC TASKS NOT DONE BY ALL: CLEAN DOWN THE M/C AT THE SHIFT END, ETC. - I.E. MAKE READY FOR NEXT SHIFT. CHECK LISTS ARE AT THE M/C BUT ARE GIVEN LIP-SERVICE	CNC MACHINIST	06/02/2002	JOURNAL	FORMATIVE	TA
23	TASK ANALYSIS INTERVIEW 2: THE JOB HAD BEGUN ON THE NIGHT SHIFT, AND THERE WAS NO HANDOVER. THE TA BEGINS AT THE 1ST OBSERVED TASK.	CNC MACHINIST	07/02/2002	JOURNAL	FORMATIVE	TA
24	AS FOR TA 2, BUT I SAW THE COMPLETE JOB.	CNC MACHINIST	07/02/2002	JOURNAL	FORMATIVE	TA
123	TECH PACKAGE LAYOUT DURING THE JOB IS COMMONLY THE SAME AMONGST ALL OPERATORS. DRAWN IN NOTEBOOK	CNC MACHINIST	07/02/2002	FIELDNOTES	FORMATIVE	TA
124	AT THE END OF A JOB IT IS NOT UNCOMMON TO FIND THE TECH PACKAGE LEFT OUT ON THE BENCH. WHEN THIS IS THE CASE, IT IS FILED WHEN THE NEXT TECH PACKAGE IS REQ'D. HOUSEKEEPING IS NOT A STRONG POINT	CNC MACHINIST	07/02/2002	FIELDNOTES	FORMATIVE	TA
125	OPERATORS ARE VERY CAUTIOUS WITH CUTS & KNOW WHEN IT MAY GET CLOSE TO GOING OVER LIMITS. THEY STEP THRO MEASURING EACH CUT. IF UNDER LIMITS THEY WILL ANALYSE WHY AND RESET THE PARAMETERS TO RECTIFY	CNC MACHINIST	07/02/2002	FIELDNOTES	FORMATIVE	TA
126	AT THE END OF A JOB THEY WILL PACK AWAY THEIR OWN TOOLS (VERNIER/MICROMETER) AS WOULD BE EXPECTED	CNC MACHINIST	07/02/2002	FIELDNOTES	FORMATIVE	TA
25	MET WITH CELL LEADER ABOUT PERFORMANCE MEASUREMENT: NO HARD MEASURES AT EACH M/C TOOL. OPERATORS & COACH HAVE A WEEKLY MEETING ABOUT TARGETS & QUALITY, BUT NOTHING DIRECT IS MEASURED IN £S!	CELL LEADER	08/02/2002	JOURNAL	FORMATIVE	MEASUREMENT
26	THE "BUSINESS DEPLOYMENT PLAN" DISSEMINATES THE STRATEGIC OBJECTIVES TO THE SHOPFLOOR. TARGETS INCL. 'SLOW WIP,	CELL LEADER	08/02/2002	JOURNAL	FORMATIVE	MEASUREMENT

	OEE, CONSIGNMENT STOCKING' - TRYING TO MAKE INTANGIBLES TANGIBLE.				
27	ME PLANNER STAKEHOLDER/TASK ANALYSIS INTERVIEW: PLANNERS' BIGGEST PROBLEM IS STANDARDISATION.	ME PLANNER	13/02/2002	JOURNAL	FORMATIVE	SA
28	ME PLANNERS COME IN AND OUT OF THE INFORMATION PROCESS FROM CONCEPTION TO EXECUTION	ME PLANNER	13/02/2002	JOURNAL	FORMATIVE	SA
29	ME PLANNERS CONSIDER THAT ISSUE CONTROL TAKES CARE OF ITSELF! THE POINT IS THAT THEY USE MANY IS TO PUT EVERYTHING IN PLACE FOR MFR. BUT THEY DON'T PICK UP THE PIECES WHEN THEY MAKE A MISTAKE!!!	ME PLANNER	13/02/2002	JOURNAL	FORMATIVE	SA
30	WITHIN ME, MANY INFORMAL METHODS HAVE DEVELOPED OVER THE YEARS TO COMPENSATE FOR THE INFLEXIBILITY OF THE SYSTEMS, SO THIS IS WHERE THE ROOT OF THE STANDARDISATION ISSUE IS.	ME PLANNER	13/02/2002	JOURNAL	FORMATIVE	SA
31	PROJECT BOUNDARIES: ME IS A WHOLE NEW BALL GAME. DRAW A LINE UNDER IT AND ONLY MODEL WHAT IS RELEVANT.	ME PLANNER	13/02/2002	JOURNAL	FORMATIVE	SA
32	THE VIEW OF ONE ME IS THAT 'IF YOU EMPOWER THE SHOPFLOOR, YOU DESKILL ME', SO HE WAS NOT VERY HELPFUL.	ME PLANNER	13/02/2002	JOURNAL	FORMATIVE	SA
33	PROCESS OWNERSHIP: ME PLANNER IS THE PROCESS OWNER! - ACCOUNTABLE FOR COST & TIME; THEREFORE COST REDUCTION IS HIS JOB.	ME PLANNER	13/02/2002	JOURNAL	FORMATIVE	SA
34	ME PLANNER VIEWS HIMSELF AS A FIREFIGHTER/FACILITATOR /TECH SUPPORT/AUDITOR	ME PLANNER	13/02/2002	JOURNAL	FORMATIVE	SA
35	IN THIS ME AREA, THEY HAVE USED A SHRED PC DRIVE TO KEEP RECORDS (SALVAGE SHEETS) THAT THEY CAN SHARE AS A KNOWLEDGE-BASE	ME PLANNER	13/02/2002	JOURNAL	FORMATIVE	SA
36	MANY PROGRAMS HAVE CHANGED BUT THE METHODS HAVEN'T. ME PLANNERS THEREFORE NEED TO DO THIS BUT DON'T UNLESS A NEW JOB IS BEGUN	ME PLANNER	13/02/2002	JOURNAL	FORMATIVE	SA

127	FROM ME DISCUSSIONS: REQUIREMENTS ARE SET BY ENGINEERING; THE PLANNER INTERPRETS THIS; THE SHOPFLOOR THEN GET THE INTERPRETTED INFO. A LOT DEPENDS ON HOW WELL THE ME INTERPRETS REQS. SO A LOT OF KNOW IS HERE	ME PLANNER	13/02/ 2002	FIELDNOTES	FORMATIVE	SA
128	ME PLANNER IS = PDM (PRODUCT DATA MGMT); TIMES; IMS1 (APPROVALS); SAP; SFDM (+ SOME USE SPREADSHEETS TO ESTIMATE STD TIMES & COST)	ME PLANNER	13/02/ 2002	FIELDNOTES	FORMATIVE	SA
37	STAKEHOLDER/TASK ANALYSIS OF ME PROGRAMMER: THE INFO USED BY OPERATORS IS GENERALLY SUPPLIED BY PROGRAMMERS (EXCEPT OP DRGS & JOB CARDS). THIS IS THEREFORE THE SIGNIFICANT INTERFACE	ME PROGRAMMER	14/02/ 2002	JOURNAL	FORMATIVE	SA
38	ME COMMUNICATION WITH NIGHTSHIFT OPERATORS IS DIFFICULT. NOTES ARE LEFT, BUT ARE NOT ALWAYS UNDERSTOOD - THIS IS THE SAME BETWEEN SHIFTS	ME PROGRAMMER	14/02/ 2002	JOURNAL	FORMATIVE	SA
42	CONCESSIONS CAN SHOW THAT MORE FREQUENT TOOL CHANGES ARE REQ'D. THIS LEADS TO THE PROGRAMMER WRITING ADDITIONAL LINES TO REMIND THE OPERATOR OF EXTRA TOOL CHANGES. THIS ALSO APPEARS ON THE M/C INTERFACE.	ME PROGRAMMER	14/02/ 2002	JOURNAL	FORMATIVE	TA
43	ONLY ONE JOB ON THE STUDIED M/CS HAS A SIMULATION. HENCE THIS IS A BIG LIMITATION TO THE USE OF SIMULATIONS	ME PROGRAMMER	14/02/ 2002	JOURNAL	FORMATIVE	SSM
44	TASK ANALYSIS INTERVIEW 4: GAPS IN THE PREVIOUS MODEL WERE FILLED.	CNC MACHINIST	06/03/ 2002	JOURNAL	FORMATIVE	TA
129	THERE ARE GAUGE 'BINS' FOR EACH JOB. THEY ALWAYS SIT ON THE EDGE OF THE BENCH. THE LEADING HAND IS RESPONSIBLE FOR CALIBRATION & REPLACEMENT. THEY CAN BE BORROWED BETWEEN LOCAL MACHINES BUT NOT OFFICIALLY	CNC MACHINIST	06/03/ 2002	FIELDNOTES	FORMATIVE	TA
130	TOOL CHANGE OBSERVED: USED A VERNIER TO CHECK EXISTING TOOL LENGTH IN HOLDER. THEN SET NEW TOOL TO SAME	CNC MACHINIST	06/03/ 2002	FIELDNOTES	FORMATIVE	TA

	LENGTH. HE DIDN'T USE(/NEED) TOOL SHEET. ALTHOUGH MANY TOOLS LOOK SAME & IDENTIFIED BY NO, THIS ONE WAS UNIQUE SO LOW RISK OF ERROR (KNOWLEDGE)					
131	OPERATORS TEND TO FILTER THROUGH INFO BY EYE AND NOT BY SHEET NOS. THEY LOOK FOR RECOGNISED PATTERNS. THIS SHOULD BE ENABLED ON SCREEN FOR THE SYSTEM TO BE USABLE	CNC MACHINIST	11/03/ 2002	FIELDNOTES	FORMATIVE	TA
49	OPERATOR REVIEW OF THE TASK MODEL BY BOTH GROUPS: SOME TERMINOLOGY NEEDED EDITING; SOME POINTS WOULD FAIL AN AUDIT AND SHOULD THEREFORE NOT BE INCLUDED; ADDITIONS WERE MADE TO THE MODEL	CNC MACHINIST	20/03/ 2002	JOURNAL	FORMATIVE	TA
52	FINAL IDEF0 MODEL DISTRIBUTED FOR REVIEW	CNC MACHINIST	03/04/ 2002	JOURNAL	FORMATIVE	TA
53	FOUND THAT OPERATORS REQUIRE MORE DIRECTION. A PASSIVE APPROACH DOESN'T STIMULATE IDEAS. I MUST PROVIDE OBJECTIVES, ETC.	CNC MACHINIST	04/04/ 2002	JOURNAL	FORMATIVE	TA
54	CHANGE OF CELL LEADER	CELL LEADER	04/04/ 2002	JOURNAL	FORMATIVE	GENERAL
55	FOUND THAT NIGHT SHIFT WERE FEELING EXCLUDED AS THEY CAN WORK SEVERAL WEEKS ON THE SAME SHIFT. I WILL BEGIN WITH EARLY STARTS TO TIE UP WITH THEM AT THE END OF THEIR SHIFT.	CNC MACHINIST	05/04/ 2002	JOURNAL	FORMATIVE	GENERAL
61	A NOTE ON GROUP DYNAMICS: OPERATORS 1,2,5,6 LISTEN BUT SAY LITTLE; OP 3 IS WILLING TO QUESTION MY METHODS AND GET THE OTHERS TALKING; OP 4 IS TALKATIVE; OP 7 IS VERY KEEN TO PROVE HIS EXPERT STATUS	CNC MACHINIST	25/04/ 2002	JOURNAL	FORMATIVE	SA
148	THEY ALREADY HAVE A WHITEBOARD FOR WRITING NOTES TO EACH OTHER, BUT IS INFORMAL & ONLY A FEW WRITE ANYTHING	CNC MACHINIST	04/07/ 2002	FIELDNOTES	FORMATIVE	TA
149	"WRITING THINGS DOWN MAKES YOU FEEL BETTER ABOUT THE JOB" OP 5	CNC MACHINIST	04/07/ 2002	FIELDNOTES	FORMATIVE	TA
5	ROUTE/JOB CARDS ARE INTEGRAL TO THE SFDM (SHOPFLOOR DATA MANAGEMENT) SYSTEM	CNC MACHINIST	23/01/ 2002	JOURNAL	INTERVENTION	GENERAL

	CONTROLLED BY SHOPFLOOR MGMT (MATERIAL CONTROLLER). THIS IS A DIFFERENT SOURCE TO THE OTHER MFG INST AND IS 'MORE' BUSINESS CRITICAL, SO WOULD BE DIFFICULT TO GET ON THE RESEARCH SYSTEM.					
9	ONCE THE TASK ANALYSES ARE TRANSCRIBED AND MODELLED, THE RESULTS CAN BE CONVERTED TO SYSTEM REQUIREMENTS AND PASSED TO JARMO TO BUILD THE FIRST PROTOTYPE.	N/A	25/01/2002	JOURNAL	INTERVENTION	SSM
10	SOURCING IS CONTENT IS A LENGTHY TASK AND SHOULD BEGIN IMMEDIATELY. ALL PAPER-BASED INFO NEEDS TO BE SCANNED AND FORMATTED AS PDF.	N/A	25/01/2002	JOURNAL	INTERVENTION	N/A
39	A SUGGESTION BY THE PROGRAMMER: OPERATORS COULD WATCH A VERICUT MOVIE AND AND LEAVE NOTES ON ATTACHED TO THE FILE TO OFFER FEEDBACK TO THE PROGRAMMER	ME PROGRAMMER	14/02/2002	JOURNAL	INTERVENTION	SSM
40	ME ALREADY USE A DIGITAL CAMERA TO CAPTURE EVIDENCE FOR CONCESSIONS. COULD A CAMERA BE USED BY OPERATORS TO CAPTURE ISSUES AND DOWNLOADED TO THE IS TO BE VIEWED BY THE ME?	ME PROGRAMMER	14/02/2002	JOURNAL	INTERVENTION	SSM
41	GAUGING IS NOT CURRENTLY WRITTEN ON THE PROGRAM, COULD IT BE FOR FASTER RETRIEVAL?	ME PROGRAMMER	14/02/2002	JOURNAL	INTERVENTION	SSM
45	COLLATING CONTENT FOR SYSTEM DEVELOPMENT: SCANNING IS THE PRACTICAL OPTION TO GET DRGS, ETC.	N/A	06/03/2002	JOURNAL	INTERVENTION	N/A
46	A STRUCTURE (BOM) FOR THE TECHNICAL PACKAGES WAS CREATED TO AID INFO COLLATION	N/A	07/03/2002	JOURNAL	INTERVENTION	SSM
47	INFO COLLATION BEGUN BY SAVING SCANNED DRAWINGS AS JPEGS	N/A	08/03/2002	JOURNAL	INTERVENTION	SSM
132	SOMETHING TO SHOW LESSONS LEARNED IS REQUIRED	CNC MACHINIST	12/03/2002	FIELDNOTES	INTERVENTION	SSM
48	GETTING A SIMUALTION MOVIE CLIP WAS NOT STRAIGHTFORWARD DUE TO TECHNICAL CONSTRAINTS. IT REMAINS	ME PROGRAMMER	20/03/2002	JOURNAL	INTERVENTION	SSM

	UNRESOLVED AT THIS POINT					
50	EARLY SUGGESTION FOR CONTENT: CREATE A FRONT PAGE FOR EACH TECH PACKAGE WITH APPROPRIATE LINKS	CNC MACHINIST	20/03/2002	JOURNAL	INTERVENTION	SSM
51	CONTINUED INFO COLLATION	N/A	20/03/2002	JOURNAL	INTERVENTION	SSM
133	VERICUT FILES ARE MASSIVE. THEREFORE NEED SHORT CLIPS IN SMALL FILES	ME PROGRAMMER	20/03/2002	FIELDNOTES	INTERVENTION	SSM
134	FROM TA IDENTIFY WHAT NEEDS TO BE VIEWED & WHEN	CNC MACHINIST	20/03/2002	FIELDNOTES	INTERVENTION	SSM
135	A LOW RESPONSE RATE FROM OPS SHOWS THAT THEY DON'T WANT TO KNOW ABOUT THE RESEARCH, JUST THE EVERYDAY STUFF	CNC MACHINIST	04/04/2002	FIELDNOTES	INTERVENTION	SSM
56	PROJECT PLAN PRESENTED TO OPERATOR 4. VERY KEEN	CNC MACHINIST	24/04/2002	JOURNAL	INTERVENTION	SSM
57	PROJECT PLAN PRESENTED TO OPERATOR 7 (CONTROL OP). KEEN	CNC MACHINIST	24/04/2002	JOURNAL	INTERVENTION	SSM
58	PROJECT PLAN PRESENTED TO OPS 3 & 5. BOTH ACCEPTED IT BUT WERE NOT OVER-ENTHUSIASTIC	CNC MACHINIST	24/04/2002	JOURNAL	INTERVENTION	SSM
59	PROJECT PLAN PRESENTED TO OPS 1 & 6. SILENTLY ATTENTIVE, BUT POSITIVE	CNC MACHINIST	25/04/2002	JOURNAL	INTERVENTION	SSM
60	PROJECT PLAN PRESENTED TO OP 2. V. POSITIVE	CNC MACHINIST	25/04/2002	JOURNAL	INTERVENTION	SSM
63	KIOSK INSTALLED WITH PRLIM CONTENT DEVELOPED FROM TASK MODEL	CNC MACHINIST	30/04/2002	JOURNAL	INTERVENTION	SSM
65	DISCUSSED KIOSK WITH OP 5. HE SUGGESTED A PROBLEMS PAGE FOR ALL TO LEARN FROM	CNC MACHINIST	30/04/2002	JOURNAL	INTERVENTION	SSM
64	CONTINUED COLLATION OF CONTENT	N/A	01/05/2002	JOURNAL	INTERVENTION	SSM
66	OPERATOR 1 HAD TROUBLE USING THE TOUCH SCREEN WHICH CAUSED HIM TO GET FRUSTRATED. I SPENT SOME TIME EXPLAINING IT ALL TO OPS 1 & 6. THERE IS HOWEVER, AN EXPECTATION OF IMMEDIATE RESULTS. CONTINUE TO EXCEED EXPECTATIONS FOR SUCCESS!	CNC MACHINIST	08/05/2002	JOURNAL	INTERVENTION	SSM

67	OBSERVATION OF OPERATORS' USE OF THE SYSTEM - REFER TO THE JOURNAL ENTRY (THIS IS EXTENSIVE QUALITATIVE DATA)	CNC MACHINIST	08/05/ 2002	JOURNAL	INTERVENTION	SSM
136	TO KEEP USERS UP TO DATE: THE FRONTPAGE OF THE SYSTEM SHOULD BE A BULLETIN BOARD: E.G. LIST UPDATES; STATE NEXT UPDATES; EXPLAIN THE RESEARCH; INVITE NEW USERS	CNC MACHINIST	08/05/ 2002	FIELDNOTES	INTERVENTION	SSM
137	WHEN THE SCREENSAVER IS INTERRUPTED, THE SCREEN RESETS TO THE HOMEPAGE. OPS DON'T LIKE THIS BECAUSE THE HAVE TO RENAVIGATE - A BIG LIMITATION	CNC MACHINIST	08/05/ 2002	FIELDNOTES	INTERVENTION	SSM
138	THE PROGRAM IS CENTRAL TO TRACKING WHERE A JOB IS. ALL OTHER INFO HANGS OFF OF THIS. SO MAKE IT CENTRAL TO THE SYSTEM	CNC MACHINIST	08/05/ 2002	FIELDNOTES	INTERVENTION	SSM
139	TO EXPAND ON THE IMPORTANCE OF THE PROGRAM, CAN WE ADD LINKS TO THE PROGRAM TO GO STRAIGHT TO RELEVANT INFO	CNC MACHINIST	08/05/ 2002	FIELDNOTES	INTERVENTION	SSM
140	THE PROGRAM IS SO COMPLEX YOU MUST ACCEPT WHAT IT IS DOING, SO IS IT REDUNDANT?	ME PROGRAMMER	08/05/ 2002	FIELDNOTES	INTERVENTION	SSM
68	AFTER INITIAL INTEREST IN THE PRELIM KIOSK CONTENT, IT WENT QUIET. THE 1ST UPDATE IS DUE TOMORROW	CNC MACHINIST	23/05/ 2002	JOURNAL	INTERVENTION	SSM
69	KIOSK NOT UPDATED DUE TO TECHNICAL CONSTRAINTS	N/A	24/05/ 2002	JOURNAL	INTERVENTION	N/A
70	SUGGESTION FOR IMPROVEMENT: HIGHLIGHT IMPORTANT LINES IN THE PROGRAM	CNC MACHINIST	24/05/ 2002	JOURNAL	INTERVENTION	SSM
71	IMPROVEMENT SUGGESTION: SPLIT SCREENS - SHOW ALL THE DIFFERENT INFO ON ONE SCREEN - LIKE THE PREVIOUS IDEA OF A FRONT PAGE	CNC MACHINIST	24/05/ 2002	JOURNAL	INTERVENTION	SSM
72	KIOSK VERSION 2 WAS INSTALLED BUT FAILED. IT REMAINED U/S FOR 3 WEEKS WHILST A SOLUTION WAS SOUGHT	CNC MACHINIST	31/05/ 2002	JOURNAL	INTERVENTION	N/A
73	USABILITY ISSUES: PROBLEMS SCROLLING THE PROGRAM IN PDF FORMAT (IF YOU'RE NOT USED TO THE CHANGE OF	CNC MACHINIST	31/05/ 2002	JOURNAL	INTERVENTION	SSM

	CONVENTION IT IS HARD TO GET USED TO)					
74	EVEN AT THIS EARLY DEVELOPMENT STAGE OP 4 HAD USED A DRG ON THE SCREEN RATHER THAN A PAPER-BASED DRG AS IT WAS "FASTER & EASIER"	CNC MACHINIST	31/05/ 2002	JOURNAL	INTERVENTION	SSM
141	POINTS ON THE KIOSK: HOMEPAGE IS GOOD BUT COULD BE CLEARER	CNC MACHINIST	05/06/ 2002	FIELDNOTES	INTERVENTION	SSM
142	TOOL SHTS ARE LISTED IN ORDER DOWN THE PAGE BUT YOU CAN'T KEEP TRACK LIKE WHEN USING A FOLDER	CNC MACHINIST	05/06/ 2002	FIELDNOTES	INTERVENTION	SSM
143	SCROLLING IN PDFS IS NOT CLEAR TO NEW USERS - DIFFERENT CONVENTION	CNC MACHINIST	05/06/ 2002	FIELDNOTES	INTERVENTION	SSM
144	LINKS FROM THE PDF PROGRAM: CAN'T BE DONE BECAUSE FOR EVERY UPDATE NEW LINKS WILL NEED TO BE CREATED. PLUS PDFS DON'T ENABLE LINKS EASILY. A SUPPORT NIGHTMARE	CNC MACHINIST	05/06/ 2002	FIELDNOTES	INTERVENTION	SSM
75	THE KIOSK WAS REPAIRED & RETURNED. HOWEVER SOME LINKS DIDN'T WORK	N/A	27/06/ 2002	JOURNAL	INTERVENTION	N/A
76	OPERATOR 1 HAD BEEN TRYING TO USE THE 'THUMBNAIL' LINKS AS DRGS WITHOUT RELIALISING THAT THERE WERE BETTER IMAGES ON THE SYSTEM	CNC MACHINIST	27/06/ 2002	JOURNAL	INTERVENTION	SSM
145	USING SOLID MODELS ON SCREEN: JUST NEED ONE MODEL PER PART, SO NAVIGATE FROM PART HOMEPAGE - ONLY ONE AVAILABLE MODEL	CNC MACHINIST	27/06/ 2002	FIELDNOTES	INTERVENTION	SSM
146	THE KIOSK IS VERY LIST ORIENTED DUE TO JARMOS AUTHORING STYLE. TRY TO DEVELOP DIFFERENT LOOKS	CNC MACHINIST	27/06/ 2002	FIELDNOTES	INTERVENTION	SSM
77	THE FIRST NOTE WAS LEFT ON THE COMMUNICATIONS TOOL TO INFORM ME OF A DRG BEING THE WRONG ISSUE	CNC MACHINIST	28/06/ 2002	JOURNAL	INTERVENTION	SSM
78	A COMMENT LEFT ON THE KIOSK WAS THAT A PROBLEMS PAGE IS REQ'D (AS PREVIOUSLY DISCUSSED)	CNC MACHINIST	03/07/ 2002	JOURNAL	INTERVENTION	SSM
79	OP 5 CONFIRMED THAT HE WANTS A PROBLEM/HISTORY PAGE LINKING THE MAIN PART PAGE TO THE PROBLEM PAGE TO ENCOURAGE USERS TO ENTER COMMENTS/ISSUES ON	CNC MACHINIST	04/07/ 2002	JOURNAL	INTERVENTION	SSM

	PARTICULAR PARTS					
80	OP 4 CONTINUED TO CHAMPION THE SPLIT SCREENS IDEA. IN HIS VIEW SPLIT SCREENS ARE A PRE-REQUISITE	CNC MACHINIST	04/07/ 2002	JOURNAL	INTERVENTION	SSM
81	DISCUSSION WITH OP 4 DETERMINED THAT LOCATION OF THE KIOSK IS IMPORTANT. IT WILL EVENTUALLY BE MOVED TO THE BEST LOCATION	CNC MACHINIST	04/07/ 2002	JOURNAL	INTERVENTION	SSM
147	PAST PROBLEMS/LESSONS LEARNED PAGE STILL NOT PRODUCED! LINKING TO DOS & DON'T WOULD BE GOOD.	CNC MACHINIST	04/07/ 2002	FIELDNOTES	INTERVENTION	SSM
150	BY WRITING INFO/KNOWLEDGE ON THE SCREEN OPERATORS WILL INTRODUCE OTHER FUNCTIONS TO IT, SO THE BOUNDARIES OF THE SYSTEM INCREASE	CNC MACHINIST	04/07/ 2002	FIELDNOTES	INTERVENTION	SSM
151	OPERATORS CURRENTLY CROSS-REF ALL INFO, SO IT SHOULD BE THAT THEY CAN DO THE SAME ON THE SCREEN - "THIS CAN ONLY BE DONE WITH SPLIT SCREENS" - OP 3	CNC MACHINIST	04/07/ 2002	FIELDNOTES	INTERVENTION	SSM
83	BUTTONS THAT INDENT WHEN YOU PRESS THEM ARE DESIRABLE	CNC MACHINIST	05/07/ 2002	JOURNAL	INTERVENTION	SSM
152	OBSERVING AN OP USING THE VIRTUAL KEYBOARD: HE WROTE HIS NOTE ON PAPER 1ST AND THEN TOOK AT LEAST 10 MINS TO WRITE IT ON THE SCREEN (30 WORDS APPROX.); BUT HE MAINTAINS ITS OK TO USE	CNC MACHINIST	10/07/ 2002	FIELDNOTES	INTERVENTION	SSM
153	CONVERTING TO SPLIT SCREENS: NAVIGATE BY INFO TYPE, NOT BY PART. THIS ALLOWS YOU TO OPEN EACH INDIVIDUAL FILE IN THE BIG PDF VIEWER (?)	N/A	10/07/ 2002	FIELDNOTES	INTERVENTION	SSM
84	KIOSK WAS UPDATED TO VERSION 3: FIXED BROKEN LINKS, ETC. & INSTALLED THE COMMUNICATIONS TOOL (PROBLEM PAGE)	N/A	17/07/ 2002	JOURNAL	INTERVENTION	SSM
85	PROBLEMS ENCOUNTERED WITH THE PROBLEMS PAGES, BUT FIXED	N/A	29/07/ 2002	JOURNAL	INTERVENTION	N/A
86	BUTTONS MODIFIED AS PREVIOUSLY REQUESTED (VERSION 3.2)	N/A	30/07/ 2002	JOURNAL	INTERVENTION	SSM
87	SPLIT SCREENS TRIAL INSTALLED ON ONE PART (VERSION 3.3)	N/A	30/07/ 2002	JOURNAL	INTERVENTION	SSM
89	TO ENABLE EFFICIENT UP-	ME	31/07/	JOURNAL	INTERVENTION	SSM

	ISSUE OF KIOSK CONTENT, ME WERE ASKED TO INFORM ME OF RELEVANT UPDATES PRIOR TO REISSUE	PLANNER/PROGRAMMER	2002			
88	ME TEAM LEADERS VIEWED THE KIOSK TO DISSEMINATE THE AIMS OF THE PROJECT	ME PLANNER	31/07/2002	JOURNAL	INTERVENTION	GENERAL
90	KIOSK CONTENT REQUIRING UP-ISSUE DONE	N/A	06/08/2002	JOURNAL	INTERVENTION	SSM
91	AN ISSUE CONTROL DATABASE WAS INSTALLED TO KEEP USERS INFORMED OF CURRENT ISSUE AT THE KIOSK, TO GET THEM TO PROMPT ME TO UP-ISSUE	N/A	07/08/2002	JOURNAL	INTERVENTION	SSM
92	THE MOVIE CLIPS ISSUE WAS REVISITED. ASSISTANCE FROM CAE STRATEGY SOUGHT	ME PROGRAMMER	07/08/2002	JOURNAL	INTERVENTION	SSM
93	JARMO FORMALLY SURVEYED USERS ABOUT USABILITY & USEFULNESS OF VERSION3.3. SPLIT SCREENS ARE MORE USEFUL BUT THE PROGRAM FRAME NEEDS TO BE WIDER	CNC MACHINIST	12/08/2002	JOURNAL	INTERVENTION	SSM
95	KIOSK UPDATED TO VERSION 4 (FINAL VERSION) WITH COMPLETE LOOK (DONE BY ME)	N/A	06/09/2002	JOURNAL	INTERVENTION	SSM
96	KIOSK REINSTALLED AND DEMONSTRATED	CNC MACHINIST	23/09/2002	JOURNAL	INTERVENTION	SSM
98	UPDATED THE KIOSK WITH NEW PROGRAMS AND DRGS; FORUM CATEGORIES CHANGED TO BE PART SPECIFIC (REBOOT PROBLEM IDENTIFIED)	N/A	01/10/2002	JOURNAL	INTERVENTION	SSM
101	UP-ISSUES REQ'D (NOTES LEFT ON THE FORUM)	CNC MACHINIST	06/11/2002	JOURNAL	INTERVENTION	SSM
102	FORUM HAS POOR USABILITY AND DOES NOT FUNCTION WELL - CREATE A NEW TOOL	CNC MACHINIST	06/11/2002	JOURNAL	INTERVENTION	SSM
107	USABILITY ISSUES WITH THE FORUM CONFIRMED WITH OP 5: THE NAME HAS NO MEANING; LINKS A RE TOO SMALL & CLOSE TOGETHER; IT'S TOO COMPLEX; "IT SHOULD BE FOR M/CISTS ONLY" - OP 4	CNC MACHINIST	13/11/2002	JOURNAL	INTERVENTION	SSM
104	USABILITY ISSUE ENCOUNTERED WITH THE PROGRAM FRAME - USERS UNHAPPY WITH THE HORIZONTAL SCROLL - CAN'T READ LIKE THAT	CNC MACHINIST	13/11/2002	JOURNAL	INTERVENTION	SSM
108	NEW "PAST HISTORY"	N/A	19/11/	JOURNAL	INTERVENTION	SSM

	DATABASE ADDED TO REPLACE THE FORUM (KIOSK NOW AT VERSION 5)		2002			
157	WRT PROGRAMS ON SPLIT SCREENS. THE PDF IS VIEWED IN THE FRAME, SO THEY HAVE TO USE THE HORIZ SCROLL BUT DON'T LIKE TO. THE COMPROMISE IS TO MAKE IT 1/2 THE SCREEN WIDTH RATHER THAN 1/4	CNC MACHINIST	19/11/ 2002	FIELDNOTES	INTERVENTION	SSM
111	KIOSK UPDATED TO VERSION 6. OP 1 REQ'D A LINK TO SHOW PROGRAMS FULL-SCREEN AS FOR OTHER PDFS; AND A LINK TO A LIST OF NEW PAST HISTORY POSTINGS.	CNC MACHINIST	20/11/ 2002	JOURNAL	INTERVENTION	SSM
160	SUGGESTION FOR PROGRAM WIDTH RESOLUTION: LINK IT TO THE VIEWER!	CNC MACHINIST	20/11/ 2002	FIELDNOTES	INTERVENTION	SSM
62	WORK ON THE RESEARCH DIARY BEGUN	N/A	26/04/ 2002	JOURNAL	SUMMATIVE	IA
82	PERFORMANCE MEASURES: SUPERVISION MEETINGS DEFINED A NEED TO GET STANDARD JOB TIMES. HOWEVER, ME WERE NOT WILLING TO OFFER THEIR STD TIME ESTIMATES FOR UNDISCLOSED REASONS. THE ALTERNATIVE IS TIME STUDY	ME PLANNER	04/07/ 2002	JOURNAL	SUMMATIVE	IA
94	BENEFITS DISCUSSION WITH SPONSOR TO FIND APPROPRIATE MEASURES (SEE WORD DOC)	N/A	21/08/ 2002	JOURNAL	SUMMATIVE	IA
154	NEED TO MONITOR THE "PROCESS TIME" OR "UNDERUTILISED TIME" TO TEST HYPOTHESIS 3. ALSO LOOK AT "FIT FOR PURPOSE"	SPONSOR	21/08/ 2002	FIELDNOTES	SUMMATIVE	IA
155	LIKE IN SMED, IDENTIFY THOSE COMMUNICATION TASKS THAT ARE EXTERNAL TO MAKE THEM INTERNAL	SPONSOR	21/08/ 2002	FIELDNOTES	SUMMATIVE	IA
97	DIARIES INTRODUCED	CNC MACHINIST	30/09/ 2002	JOURNAL	SUMMATIVE	IA
99	GO LIVE - SUMMATIVE EV. BEGAN	CNC MACHINIST	01/10/ 2002	JOURNAL	SUMMATIVE	IA
100	KIOSK HAD BEEN U/S FOR 3 WEEKS DUE TO POWER FAILURE. NO SUPPORT DUE TO VACATION	N/A	06/11/ 2002	JOURNAL	SUMMATIVE	IA
103	COMMENT ON THE COMPLETION OF DIARIES: " IT'S A PAIN IN THE NECK, BUT i CAN SEE WHAT YOU'RE TRYING TO DO"	CNC MACHINIST	06/11/ 2002	JOURNAL	SUMMATIVE	IA
105	WHEN DISCUSSING THE	CNC	13/11/	JOURNAL	SUMMATIVE	IA

	JOB WITH ENGINEERS, OP 3 QUICKLY FOUND THE DRAWING HE WAS LOOKING FOR ON THE KIOSK, BUT COULDN'T FIND THE FEATURE BECAUSE HE HAD AN AUDIENCE. HE THEREFORE WENT TO THE PAPER DRAWING	MACHINIST	2002			
106	OBSERVATION OF VIRTUAL KEYBOARD USE SEEMED SLOW TO ME, BUT USERS SAID THEY WERE HAPPY WITH IT	CNC MACHINIST	13/11/ 2002	JOURNAL	SUMMATIVE	IA
156	OP 5 FRUSTRATED BY DISORGANISED PAPER SYSTEM SO USES THE KIOSK INSTEAD. (HIS PERSONAL JUSTIFICATION FOR USING IT)	CNC MACHINIST	13/11/ 2002	FIELDNOTES	SUMMATIVE	IA
109	PAST HISTORY DATABASE USE INCREASED GREATLY BECAUSE IT MET REQUIREMENTS	CNC MACHINIST	19/11/ 2002	JOURNAL	SUMMATIVE	IA
110	CELL LEADER INTRODUCED RECORD BOOKS AT ALL WORKSTATIONS TO RECORD ISSUES ON EACH SHIFT. THIS POORLY HANDLED IMPLEMENTATION IMPACTED PARTICIPANTS VIEWS OF MY DIARIES.	CNC MACHINIST	20/11/ 2002	JOURNAL	SUMMATIVE	IA
112	THE LEADING HAND WAS INTRODUCED TO THE PAST HISTORY PAGES. A NOTE REFERRED TO HIM & HE ACTIONED A TASK AND POSTED A REPLY	LEADING HAND	20/11/ 2002	JOURNAL	SUMMATIVE	IA
158	PROGRAM FORMAT IS AN ISSUE. IF THE ORIGINAL DOCUMENT WAS MORE FLEXIBLE, LINKS, ETC COULD BE ADDED, & A BETTER LAYOUT USED	CNC MACHINIST	20/11/ 2002	FIELDNOTES	SUMMATIVE	IA
159	OPS 1 & 3 FOUND NOT TO BE USING THE ON-SCREEN PROGRAMS DUE TO RESTRICTED WIDTH	CNC MACHINIST	20/11/ 2002	FIELDNOTES	SUMMATIVE	IA
113	KIOSK BECOMING UNSTABLE DUE TO THE UNRESOLVED REBOOT ISSUE. HOWEVER, STILL ALE TO FUNCTION	N/A	27/11/ 2002	JOURNAL	SUMMATIVE	N/A
114	SUGGESTED FUTURE USERS FROM OP 4: TIE-IN MAINTENANCE SO THAT THEY CAN REFER TO THE SCREEN FOR PREVENTIVE MAITENANCE DATA	CNC MACHINIST & MAINTENANCE	04/12/ 2002	JOURNAL	SUMMATIVE	IA
161	A MAJOR M/C TOOL ISSUE HAS BEEN DISCUSSED FACE-TO-FACE AND MEMOS WRITTEN ON PAPER, BUT THE KIOSK WAS NOT USED. THIS IS A	CNC MACHINIST	04/12/ 2002	FIELDNOTES	SUMMATIVE	IA

	BOUNDARIES ISSUE - THE COACH & CELL LEADER ARE OUTSIDE OF THE BOUNDARY					
162	THE NIGHTS OP LEFT A PAPER NOTE FOR THE DAYS OP BUT DIDN'T USE THE SCREEN. IT WAS TOO IMPORTANT TO LEAVE ON THE SCREEN RISKING IT NOT BE SEEN. THIS SHOULD BE ADDRESSED USING ON-SCREEN ALERTS OR E-MAIL	CNC MACHINIST	04/12/2002	FIELDNOTES	SUMMATIVE	IA

Sorted and filtered fieldnotes

Appendix D – Cost Benefit Analysis

Cost Benefit Analysis is provided to support the business implications of this research, as discussed in chapter 7. This analysis finds an estimated annual saving of £50,000 for a CNC machine shop using a kiosk-based information system, such as that described at the evaluation setting. The payback on such an investment is estimated to be 3 years. Estimates are based upon data from the evaluation research setting, unless otherwise stated.

Existing information system cost estimates

Category	Cost description	Resource	Estimated man hours per technical package	Estimated hourly rate (£)	Estimated annual cost (£)
Creation	Methods planning	ME Planner	24	£66	£1,584
	Engineering drawings creation	ME Planner	24	£66	£1,584
	Part program creation (electronic)	ME Programmer	32	£66	£2,112
	Part program verification (electronic)	ME Programmer	8	£66	£528
	Part program creation (hard copy)	ME Programmer	4	£66	£264
	Tool selection	ME Programmer	16	£66	£1,056
	Tool drawings creation	ME Programmer	24	£66	£1,584
	Download part program to DNC	ME Programmer	1	£66	£66
	File engineering drawings and duplicate	ME Planner	8	£66	£528
	File tool drawings and duplicate	ME Programmer	8	£66	£528
	Update individual electronic information items periodically	ME Planner	160	£66	£10,560
	Update individual electronic information items periodically	ME Programmer	320	£66	£21,120
	Update individual paper-based information items periodically	ME Planner	40	£66	£2,640
	Update individual paper-based information items periodically	ME Programmer	80	£66	£5,280
Storage	Record & cross-reference technical package file locations	ME Planner	2	£66	£132
	Save electronic files to server	ME Programmer	1	£66	£66
	Update individual electronic information items periodically	ME Planner	8	£66	£528
	Update individual electronic information items periodically	ME Programmer	8	£66	£528
	Update individual paper-based information items periodically	ME Planner	32	£66	£2,112
	Update individual paper-based information items periodically	ME Programmer	32	£66	£2,112
Distribution	Duplicate, laminate & bind paper-based engineering drawings	ME Planner	8	£66	£528
	Distribute paper-based engineering drawings & provide instructions	ME Planner	4	£66	£264
	Duplicate & bind paper-based tool drawings	ME Programmer	8	£66	£528
	Distribute paper-based tool drawings provide instruction	ME Programmer	4	£66	£264
	Duplicate & bind paper-based part program	ME Programmer	4	£66	£264
	Distribute paper-based part program and verify manually	ME Programmer	40	£66	£2,640
	Update individual paper-based information items periodically	ME Planner	48	£66	£3,168
	Update individual paper-based information items periodically	ME Programmer	224	£66	£14,784
Control	ME local provision for quality assurance of electronic information	ME Programmer	8	£66	£528
	ME local provision for quality assurance of paper-based information	ME Planner	16	£66	£1,056
	Drawing store local provision for quality assurance of paper-based information	Drawing store operator	80	£57	£4,560
	Shopfloor local provision for quality assurance of paper-based information	CNC machinist	8	£64	£512
	Departmental provision for quality assurance of electronic information	ME Quality representative	24	£66	£1,584
	Departmental provision for quality assurance of paper-based information	ME Quality representative	40	£66	£2,640
	Quality assurance audit of electronic information	Quality engineer	40	£66	£2,640
	Quality assurance audit of paper-based information at drawing stores	Quality engineer	40	£66	£2,640
	Quality assurance audit of paper-based information at shopfloor	Quality engineer	40	£66	£2,640
Total			**1468**		**£96,152**

Operational cost estimates for the existing paper-based system

Reengineering and kiosk information system implementation cost estimates

Category	Cost description	Resource	Estimated man hours	Estimated hourly rate (£)	Estimated total cost (£)
Reengineering	Analyse current ME office practice	Consultant	40	£70	£2,800
	Analyse current drawing store practice	Consultant	24	£70	£1,680
	Analyse current shopfloor practice	Consultant	40	£70	£2,800
	Reengineer ME office practice to align with electronic information system	ME representative	40	£66	£2,640
	Close drawing store	ME representative	40	£66	£2,640
	Reengineer shopfloor practice to align with electronic information system	ME representative	40	£66	£2,640
	Train & educate staff	ME representative	120	£66	£7,920
Implementation	Configure server/network infrastructure	IT staff	80	£64	£5,120
	Install kiosk hardware and infrastructure	IT staff	120	£64	£7,680
	Configure software infrastructure	IT staff	40	£64	£2,560
	Kiosk hardware & software purchase	n/a	n/a	n/a	£120,000
Total			**584**		**£158,480**

Note: Estimated kiosk purchase cost is based upon an estimate of £4,000 per unit for a machine shop requiring 30 units

Implementation cost estimates for a kiosk-based system

Reengineered information system cost estimates

Category	Cost description	Resource	Estimated man hours per technical package	Estimated hourly rate (£)	Estimated annual cost (£)
Creation	Methods planning	ME Planner	24	£66	£1,584
	Engineering drawings creation	ME Planner	24	£66	£1,584
	Part program creation (electronic)	ME Programmer	32	£66	£2,112
	Part program verification (electronic)	ME Programmer	8	£66	£528
	Part program creation (hard copy)	ME Programmer	0	£66	£0
	Tool selection	ME Programmer	16	£66	£1,056
	Tool drawings creation	ME Programmer	24	£66	£1,584
	Download part program to DNC	ME Programmer	1	£66	£66
	File engineering drawings and duplicate	ME Planner	0	£66	£0
	File tool drawings and duplicate	ME Programmer	0	£66	£0
	Update individual electronic information items periodically	ME Planner	160	£66	£10,560
	Update individual electronic information items periodically	ME Programmer	320	£66	£21,120
	Update individual paper-based information items periodically	ME Planner	0	£66	£0
	Update individual paper-based information items periodically	ME Programmer	0	£66	£0
Storage	Record & cross-reference technical package file locations	ME Planner	0	£66	£0
	Save electronic files to server	ME Programmer	1	£66	£66
	Update individual electronic information items periodically	ME Planner	8	£66	£528
	Update individual electronic information items periodically	ME Programmer	8	£66	£528
	Update individual paper-based information items periodically	ME Planner	0	£66	£0
	Update individual paper-based information items periodically	ME Programmer	0	£66	£0
Distribution	Duplicate, laminate & bind paper-based engineering drawings	ME Planner	0	£66	£0
	Distribute paper-based engineering drawings & provide instructions	ME Planner	0	£66	£0
	Duplicate & bind paper-based tool drawings	ME Programmer	0	£66	£0
	Distribute paper-based tool drawings provide instruction	ME Programmer	0	£66	£0
	Duplicate & bind paper-based part program	ME Programmer	0	£66	£0
	Distribute paper-based part program and verify manually	ME Programmer	0	£66	£0
	Update individual paper-based information items periodically	ME Planner	0	£66	£0
	Update individual paper-based information items periodically	ME Programmer	0	£66	£0
	Collate electronic technical package and download to kiosk	ME Programmer	2	£66	£132
Control	ME local provision for quality assurance of electronic information	ME Programmer	8	£66	£528
	ME local provision for quality assurance of paper-based information	ME Planner	0	£66	£0
	Drawing store local provision for quality assurance of paper-based information	Drawing store operator	0	£57	£0
	Shopfloor local provision for quality assurance of paper-based information	CNC machinist	0	£64	£0
	Departmental provision for quality assurance of electronic information	ME Quality representative	24	£66	£1,584
	Departmental provision for quality assurance of paper-based information	ME Quality representative	0	£66	£0
	Quality assurance audit of electronic information	Quality engineer	40	£66	£2,640
	Quality assurance audit of paper-based information at drawing stores	Quality engineer	0	£66	£0
	Quality assurance audit of paper-based information at shopfloor	Quality engineer	0	£66	£0
Total			**700**		**£46,200**

Note: Grey rows are obsolete in new information system

Operational cost estimates for a kiosk-based system

Resource	Estimated salary (£)	Annual hours worked	Estimated hourly rate (£)	Estimated overheads per hour (£)	Estimated hourly rate plus 100% overheads (£)
Manufacturing engineer	£28,000	1,739	£16	50	66
Drawing store operator	£12,000	1,739	£7	50	57
CNC machinist	£24,000	1,739	£14	50	64
Quality engineer	£28,000	1,739	£16	50	66
Consultant	£35,000	1,739	£20	50	70
IT staff	£24,000	1,739	£14	50	64

Note: Consultancy rate is based upon current academic consulting rates at Cranfield University

Hourly labour rate estimates for inclusion in the 3 previous tables

Summary information

Estimated annual cost of existing system	£96,152
Estimated annual cost of new system	£46,200
Estimated annual cost saving	**£49,952**
Estimated implementation cost	£158,480
Estimated payback (years)	**3**

Estimated annual cost saving and payback of a kiosk-based system[76]

[76] Note: cost estimates are for a single machine shop of 30 CNC machine tools, as observed at the evaluation setting. Assuming that all machine shops within Rolls-Royce are approximately the same size, equivalent cost savings are possible and a 3 year payback can be applied across the organisation.