Human Mismatches in Machining

by

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Dedicated to
my late father Hj.Abdul Rani bin Hj.Ali,
my mother Hajjah Teh binti Hj. Salleh,
my wife Noorhaliza binti Ayob,
my children Fatin Haziqah,
Shafiq Shahmi,
Muhammad Afifi,
Ahmad Faiz,
Farah Liyana, and
my late brother Noorhani bin Abdul Rani

Abstract

This main objectives of this study were to examine human aspects of machining and to obtain an understanding of the issues within the broad context of manufacturing. Emphasis was placed on operator mismatches and the relationships of these to basic human characteristics and the preferred levels of automation from the operators' perspective with regard to turning operations.

The literature survey showed ample evidence that supported the need for such an investigation. A methodology i.e. the matching of human tasks and mismatches method was developed as a vehicle to provide qualitative and quantitative information to explain the phenomena and to assist in the collection of data to test the hypotheses for a number of related predictions.

For a combined group of skilled and unskilled operators, significant relationships were established between mismatches and skill, self-confidence, trust, work experience and age; between self-confidence and skill, trust, work experience and age; between trust and skill; and between preferred levels of automation and mismatches. However, results from the study showed that there were no significant relationships between trust and work experience and age; and between preferred levels of automation and skill, self-confidence, trust, work experience and age.

Meanwhile, for skilled operators alone, a significant relationship was established between self-confidence and trust, but there was an absence of relationships between mismatches and skill, self-confidence, trust, work experience and age; between self-confidence and skill, trust, work experience and age; between trust and skill; work experience and age; and between preferred levels of automation and mismatches, skill, self-confidence, trust, work experience and age.

Subjectively evaluated operator preferences for levels of automation have been determined by questionnaire but formal relationships between the preferred levels of automation and skill, self-confidence, trust, work experience and age have not been established.

Generally there is a need of further study in the area and this is crucial before a major impact in manufacturing environment could be observed.

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INTRODUCTION

1.1. Introduction

This research highlights human factors issues in machining tasks by examining the problems of mismatches in machining tasks and their relationships with various human characteristics including age, skill, work experience, self-confidence, level of trust and preferred levels of automation. Mismatches refer to incompatibilities, inappropriateness, unsuitabilities or inconsistencies (Urdang, 1991). In this thesis, mismatches in task performance within a manufacturing environment are considered with an emphasis on turning operations. These are committed by human operators and thus it is inevitable that the issue is focussed on people. Like errors, various human characteristics may influence the occurrence of mismatches and hence an in-depth study of the matter is useful to reinforce and extend existing knowledge especially in the uncertain area between humans and the machines that they use (i.e. the human-machine interface).

This introductory chapter presents a brief summary of the research, the research objectives and the research hypotheses within the broad context of manufacturing engineering.

The thesis is structured to show the development of the research from the review of literature, development and generation of the hypotheses, the techniques adopted, hypothesis testing, presentation of results, discussion, conclusions and recommendations.

1.2. Background to the Problem

1.2.1. The need for automation

Hannam (1996) identified three factors that are central to meeting a manufacturing company's business strategy - a reduction in lead times, a reduction of costs and a reduction of inventory. Frequently, the first two of these may be tackled by increasing levels of automation. Beyond these efficiency and productivity reasons, there may be other factors such as a desire for change from the conventional to the latest, and from non-automation to automation. In simple terms, automation may be considered as the "in" thing to some people. In some cases, and for various reasons, the need for change may not be justified and is a form of "technological push" that may have little consideration for users.

The needs and functions of automation may vary according to the circumstances. However, a common feature is the indecisive meeting point between manual and automatic functions essential for equipment to operate according to the designers' intention. A relevant example can be found in machine tools. A wide variety of lathes can be found ranging from completely manual devices (possibly used in a home workshop) to fully automated machines used in the manufacture of complex aerospace parts.

By and large automation in industry is undertaken to replace manual work for reasons of manufacturing efficiency with the belief that the full benefits of automation far surpass its disadvantages. However, productivity increases, quality improvement, lower overall cost and shorter lead times may not necessarily outweigh the negative aspects of automation which include operator alienation, the need for re-training, waste of operators' skills and the higher capital costs. Many of the negative aspects of automation are qualitative and this results in it being difficult to objectively balance them against the benefits. Rather, analysis by equivalence and providing balances between the positive and negative may be the best means of achieving some logical comparisons. Some aspects of this approach are presented in this thesis.

The intention of this research was to study the specific area of allocation of function for manual machining operations by focussing on mismatches between operators' actions and the expected tasks corresponding to particular operations. Such a study highlights the human factors issues, particularly for machining operations involving human operators.

1.2.2. Benefits and costs of automation

Automation brings radical changes to plants and industries which may not be compatible to the people involved in production. A systematic method should be employed in the approach to automation (Boyd, 1988). There are numerous reasons for automating (Groover, 1984), but the cost in terms of capital investment, utilisation of conventional skills, employee participation, retraining, under-utilisation of conventional machines, conversion of factory layouts and re-definition of human roles in the activities of automation could be tremendous (Assad, 1988).

Some jobs are even eliminated from the shop floor completely (Arrigo, 1988). Full automation may be a wise move in financial terms, but may reach unacceptable limits if the technological and organisational leap is too great and the human resources trail far behind (Chorafas, 1990). Macro studies of automatisation, including the human aspects, are needed to enable better understanding of the issues. Problems may arise if operator-less processes become a reality in the future. These aspects clearly indicate that automation is not something which always fulfills its promise (Hannam, 1985) and its widespread implementation urgently needs major re-thinking.

The loss of human skill and tacit knowledge are often the price of automation. Jones (1983) recommended the utilisation of tacit craft knowledge in automated systems but Lawler (1992) observed that the use of operators' skill and tacit knowledge had been ineffective in such systems. It may be that this is a natural consequence that follows the implementation of automated systems which tend to turn humans into "live robots". It is stated that human needs, skill, creativity and potential should be the focus of human centred technological systems (Gill, 1994), but an investigation is required to achieve a better balance between manual and automated systems. This calls for a critical analysis of human performance, including mismatches, and should commence on manually-operated systems.

1.2.3. Role and importance of humans

Even in highly automated systems, it is generally accepted that the human operator still has an important function in the complete man-machine system. Tasks carried out by operators in these systems are not without flaws (due to imperfect interaction with machines) but rather several potential discrepancies could arise between technical equipment and the human contribution to system performance. For example, in monitoring tasks maintaining pace with the machine gives the operator the problems of maintaining vigilance, misjudgement and the stress resulting from maintaining a high level of control skill. This rigidity of control procedures could be inappropriate in critical and emergency situations. Generally, there is potential for a decrease in task performance, possible damage to the system and negative effects for the operator resulting from dissatisfaction, loss of self-confidence and lack of trust in the equipment (Parsons, 1985), (Muir, 1987), (Lee and Moray, 1994).

Research efforts have been more inclined towards either the mechanical or sociological aspects of manufacturing. There has been comparatively less research in the area intermediate to both; namely the performance of human operators in machining tasks. However, there are trends indicating a strong interest in human aspects of technology and its role for performance enhancement. A human factors specialist is particularly concerned with the input to the human from machines and the actions of the human performed on the machine, and also with the nature of the inputs and outputs from these processes and how errors can occur among them (Proctor and Zandt, 1994).

1.2.4. Nature of the problem

In manufacturing, research to optimise output has focused primarily on the physical and mechanical aspects of manufacturing systems with relatively little attention given to operational aspects of machining involving human intervention. Physical and mechanical developments seem to surpass the human factors development because humans are the least understood by specialists where the margin of compromise between human and machine is wide enough to accomodate trade-offs. Take a cutting process as an example; human functions such as selection and decision-making are examples of human intervention which may contribute to achieve optimum output. Quantification of human functions and hence human performance in machining is a less developed area of research because machining performance by humans depends on several complex factors such as cognitive and behavioural characteristics.

Evidence shows that the final result of a design process for a man-machine system in allocating functions to either man or machine is based not so much on human or social aspects, but more on technological and economic criteria (Ekkers et al, 1979). For example in welding technology, there are two reasons for supervision of the welding process by means of technical sensors (Becken, 1970). The first is associated with the development of automation and the second is the nature of the task especially when welding at difficult or dangerous locations. However, "robots have limitations which cause them to act like a blind human working with tools" (Lindstedt and Olsson, 1992). Similarly, automation is no exception and the technology may be viewed as equivalent to a tireless and hardworking human severely lacking in senses, emotions, feelings, ego, satisfaction and other characteristics inherent to human nature.

1.2.5. Current research around this problem

It is foreseen that technology may not be used to completely replace people. Rather it will be used to semi-automate their tasks (as depicted by Figure 1.1), to help them make better and faster decisions and carry out more appropriate and timely actions.

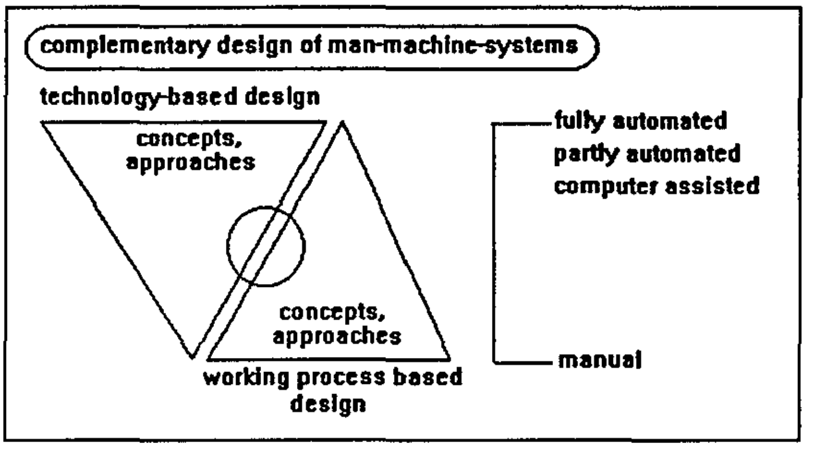


Figure 1.1 The Dual Design Approach of Man-Machine Systems
(Source : Bohnhoff/Henning (1990) extracted from Wobbe (1992))

More effective combinations of technology and people are essential for a solution to a set of requirements (Weston, 1994). Figure 1.2. shows activities which could be automated. For both manual and automated machining operations, an optimum combination of operators, tasks and machines is essential for greater production efficiency. Although this requirement has been mentioned time and time again, pin-point accuracy in deciding the meeting point between manual work and automation is virtually absent.

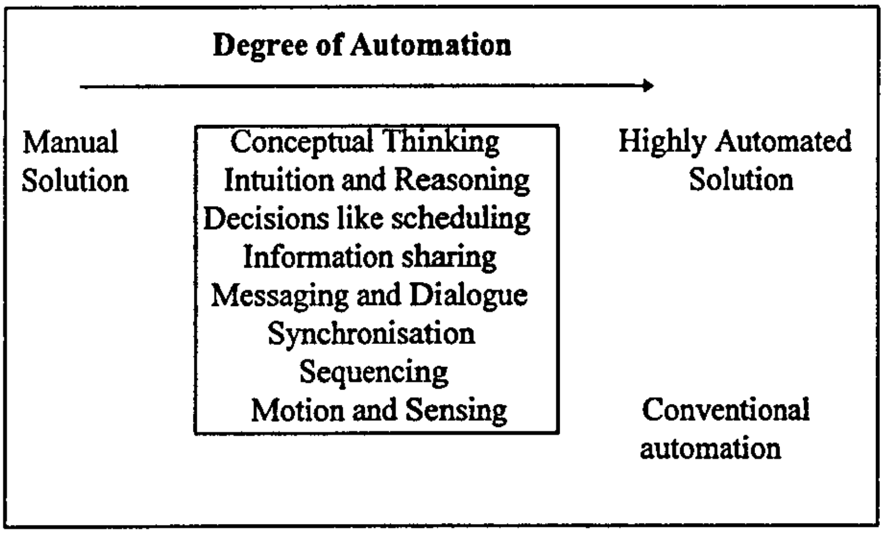


Figure 1.2 Activities which could be automated
(Source : Weston, 1994)

There are also no comprehensive empirical statistics of accidents involving advanced manufacturing systems (AMS)-such as near misses, accidents, and losses (Sheehy and Chapman, 1988). Similarly, mistakes, errors and mismatches for AMS are not available and an investigation to assess the underlying problem in machining operation both for manual and automated machining needs to be undertaken.

Against this background, the studying of mismatches and the establishment of the levels of automation preferred by operators in manual turning operations is of significance and contributes to our knowledge of advanced manufacturing.

1.3. The Area of Interest

1.3.1. An overview of the research area

The emphasis of this study is mainly on the performance of human operators in turning operations. Generally the basic idea supporting the area of research is derived from Balint and Iken (1994), according to whom, the history of man-machine systems may be split into the following five periods (or five generations of MMS) :

Period 0	:	No automation - all processes controlled by humans.
Period I	:	"Hard" automation (the period before the emergence of computing machines)
Period II	:	Automation aided humans (early automation aids humans but humans do most of the jobs).
Period III	:	Human aided automation (high level of automation takes over most tasks while humans just aid the processes by intelligent supervision).
Period IV	:	Human/ automata symbiosis (optimum task division between man and machine) - the future.

The research reported in this thesis is significant in the context of these five generations of MMS as it provides some insights into the relationship between automation and human characteristics i.e. human performance.

A suggested model of the research area to study the human performance in manufacturing is as shown in Figure 1.3. The flowchart suggests that in machining operations, inputs comprised of software and hardware, information and sensors, humans and machines, reasoning and materials, etc., could be sub-divided into the two main categories of technical and human functions. Technical functions result from machine performance while human functions result from human performance. Interactive performance is the resultant of both machine and human performance combined which produces mismatches, manufacturing discrepancies, errors

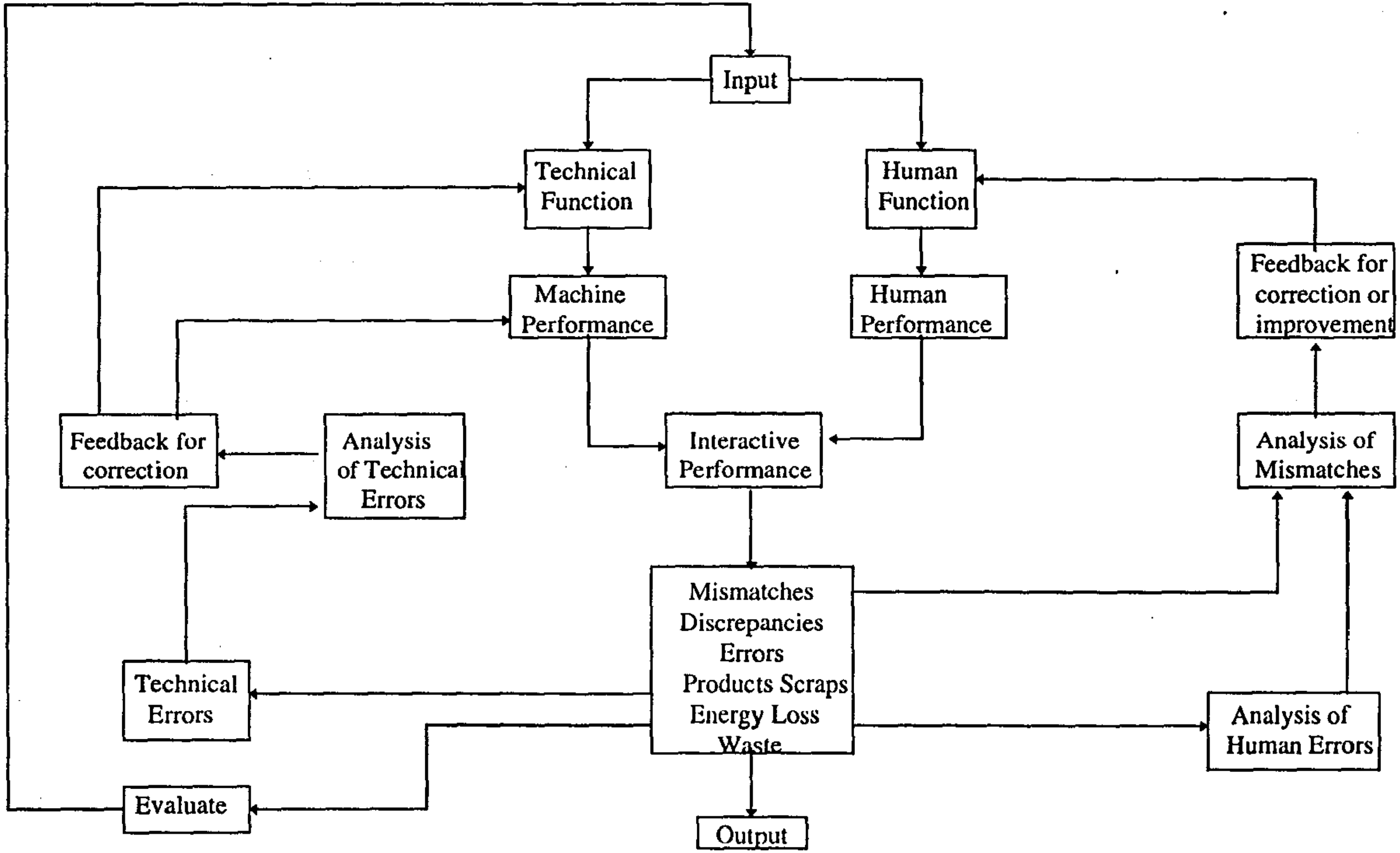


Figure 1.3 A Model of the Research Area

(technical and human), products, energy loss, waste, etc as the outputs. Technical errors may be evaluated and used as feedback for the correction of technical functions and machine performance while mismatches may be analysed and used as feedback for correction or improvement of human functions and human performance.

1.3.2. The specific area

The study involves analysing typical tasks in turning operations. It may be considered as a study into task elements of machining activities which translate into a quantification of mismatches, and the establishment of relationships between variables and psychophysical characteristics. This in turn provides information that is considered to be very useful in making decisions related to automation. The research has the objective of establishing how well humans perform machining tasks in manual turning operations. Human performance in relation to ergonomics or human factors aspects can be a very subjective area. The operators' performance is based on the relationship between human tasks and mismatches in machining operations. An ideal combination of tasks and operators' responses in performing the machining operations gives rise to perfect matches or all match-up or without mismatches. It has been suggested that "an appropriate match seems needed between the load presented by the largely mental tasks of automation and the ability, skill and experience of the operator" (Shackel, 1967).

Matching, like "safety is an artificial and operationally negative concept. Artificial in that matching performance is merely a subset of acting effectively, or skillfully. Negative in that the whole approach has been to prevent certain kinds of undesirable activity rather than to facilitate desirable activity" (Singleton, 1989). Matching and safety are similar in the sense that a safe or a matching event may or may not occur between a human and a machine. Mismatchings correspond to unsafe events which are unwanted and cause losses that should be avoided for greater productivity and efficiency.

People make mistakes all the time. "It is when and where they occur that turns them from innocuous, unnoticed and self-corrected performance discrepancies into respectable events" (Whalley, 1988). Mismatches may occur during machining operations using manual or automated machines. Mismatches may be considered as unwanted deviations in performance output and have the characteristic of classifying types of human errors based on the causes indicated. Although manual machining operations differ greatly to those in automated machining operations, common categories of mismatches may result in common categories of machining operations such as selection, setting-up and inspection. These mismatches will vary between operators of differing levels of skill.

Reason (1987) pointed out that most operator errors arise from a mismatch between the properties of the system as a whole and the characteristics of human information processing. Thus, mismatches between operators and equipment need to be identified by a series of analyses of user tasks and relevant operations involved with particular equipment.

Research into trust and self-confidence of operators on machine systems have been focussed more on automated systems rather than manual machine systems (Muir, 1994, Muir and Moray, 1996, Lee and Moray, 1994). However, an understanding of trustworthiness and self-confidence on manually-operated machine systems provides the basis for further development of those characteristics on automated systems. Therefore, this study highlights issues related to trust and self-confidence on manually-operated machine systems in order to strengthen and enhance previous findings on those issues related to automated machine systems.

This leads to a human engineering approach which concentrates on the operator. Human tasks and mismatches are in focus because both might contribute to human error and have effects on work efficiency in terms of individual, group and whole company production rates.

In this study, turning operations on manual centre-lathes were chosen for investigation. The results should prove beneficial to automated systems where a similar approach could be applied to other equipment in manufacturing processes.

1.3.3. Parameters related to the specific area

Figure 1.4 provides a model which shows the link between the area of research interest and the development of the methodology used in this study i.e. the human task mismatch matching method.

Under ordinary circumstances, a task is performed when a human acts with a machine in a workspace within a controllable environment under a certain manageable organisation. Various contributing factors result in action. If a human is one of these factors, the resultant act may be considered as a human performance. A person's well being influences his or her own performance and there are many interactions in the relations among person, task, conditions and results of the effort (Kroemer, 1993). Various contributing factors include (Galer, 1987) :

a) Human	:	gender, age, physique, size, experience, ability, intelligence, motivation, mood, skill, training, education, etc.
b) Machine	:	panel layout (interface design), controls, displays.
c) Workspace	:	tool layout, posture, reach, machine size, adjacent machines, structures, chairs etc.
d) Environment	:	physical (light, noise, heat, gas) chemical, biological (microbes), physiological.
e) Organisation	:	pay, security, hierarchy, profit etc.

Due to the subjectivity and complexity of some of the above factors, it is almost impossible to quantify the influence or the effect of each component and to obtain

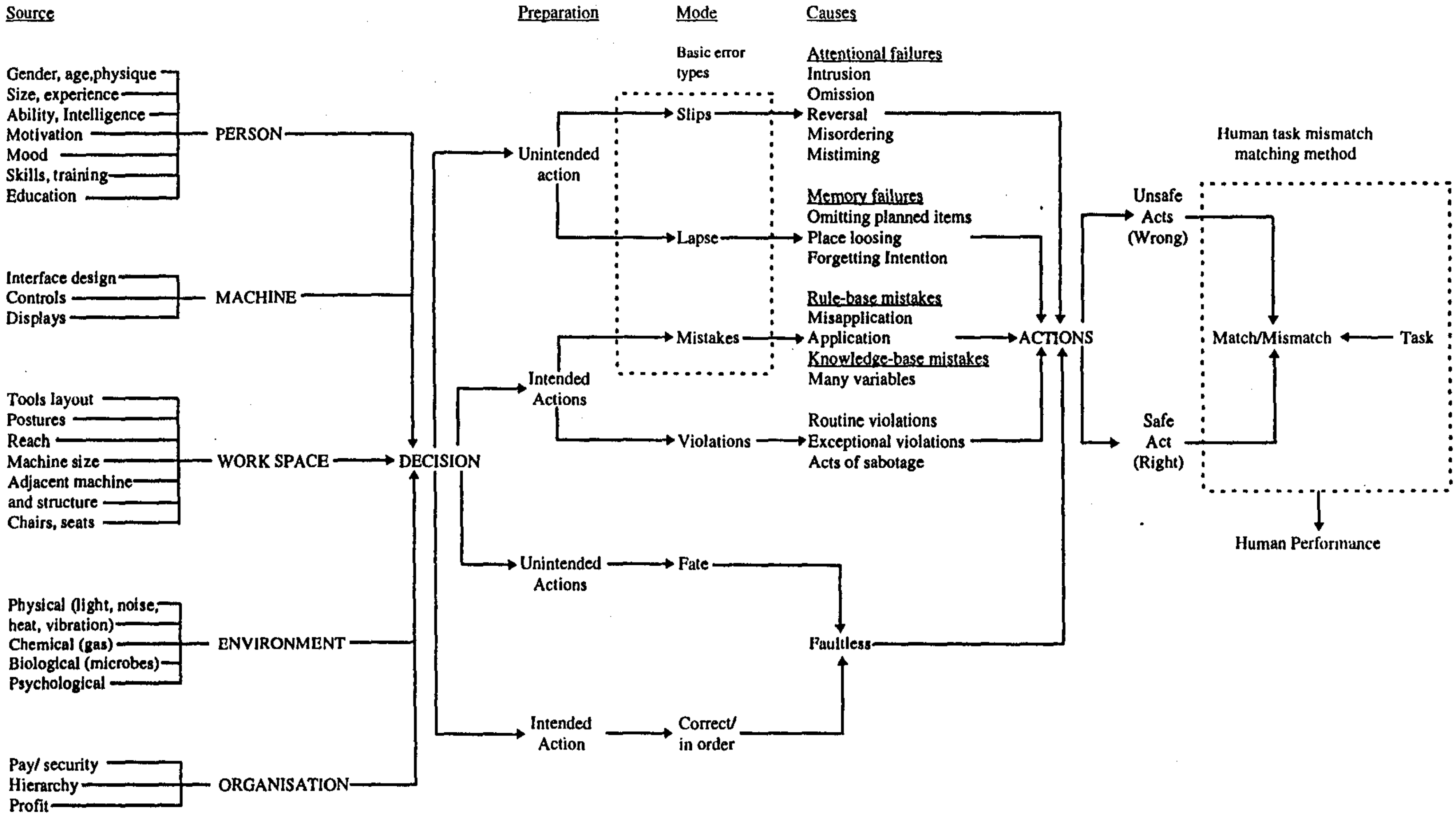


Figure 1.4 A suggested model indicating the area of interest and the development of human task mismatch matching method.
(Adapted from Reason (1990) and Galer (1987))

an integral value to represent the human performance of a task. However, close study of the actions performed by humans could be used to investigate issues arising.

An action may be sub-divided into safe and unsafe acts (Reason, 1990). "In any unsafe situation, a lot of complicated and related events follow from an equally complicated set of preceding events which could be called causes" (Singleton, 1976). A safe act may be considered as ideal and perfect because it results in higher productivity and hence prosperity. In machining, there could be three outcomes for an action (Morawski, 1978).

a) action is wrong and fault is corrected : accepted but delayed.

b) action is wrong and fault is NOT corrected : rejected.

c) action is correct : accepted and without delay.

Slips, lapses and mistakes are three basic error types. Slips (actions are not in accordance with the actions actually intended (Reason, 1990)) and lapses (slight error especially one caused by forgetfulness, weakness or inattention (Hawkins et al, 1993)) are the modes for unintended action while mistakes (actions performed as intended but with effects not in accordance with the person's intended goal (Reason, 1990)) and violations are the modes for intended actions. Slips, lapses and mistakes are a result of attentional failures, memory failures and rule-based mistakes respectively. The problems of mismatches in machining operations are centred on people. The actions of individual operators result in matches or mismatches between tasks and actions. The ideal human performance in machining operations may be affected by mismatches. In this thesis inappropriate, incompatible, unsuitable or inconsistent actions are considered mismatches, that if remain uncorrected would become errors.

An overview of the parameters involved is shown in Figure 1.4.

Therefore, this study is carried out to investigate issues, characteristics, problems and some effects on task elements resulting from machining carried out by human operators. The study focusses on manual turning operations as this is considered to be a basis upon which to consider the automation of turning operations.

The study does not attempt to research human performance across all types of industry. Instead, the manufacturing sector has been selected with human performance in conventional machining processes as the focal point. Generalisation of the findings to a broader range of processes and industries is attempted in Chapter Seven.

1.4. The Problem

It is observed that a machine tool while being operated by an operator creates a considerable number of problems that must be overcome if the machining process is to function satisfactorily. These problems arise in performing the selection, setting-up and inspection functions administered by an operator, who would normally :

a) select tools and accessories,
b) inspect tools,
c) set-up the tool,
d) set-up the workpiece,
e) set-up the cutting speed, feed and travels,
f) monitor the cutting tools' performance and condition,
g) replace any worn or defective tools,
h) assess the quality of the workpiece during machining,
I) change speeds and feeds if required,
j) respond to any unusual conditions that are seen or heard during a cutting operation,
k) measure the component after machining,
l) etc.

The interaction between human operator and machine in any machining operation is highly complex and a considerable amount of training is required to achieve the skills prior to actual machining. Designing an automatic machine tool requires a perfect balance between what operators could readily offer to that which a machine requires to perform without interaction problems.

In the unmanned situation (full automation), a high degree of artificial intelligence is necessary to mirror the experience of fully-skilled operators and their instinctive reactions, so as to provide the type of expertise associated with human involvement. Thus, it should be realised that human aspects and their involvement or participation are crucial to the success of automated manufacturing (Rammel and Holland, 1988), (Draper, 1986).

Any automated machine needs flexibility to remain competitive. The machine-centred focus of technological innovations in recent times has not only removed the "tool" from the hand of the skilled craftperson and inserted it into the machine, but it is separating human knowledge and experience from the head of the skilled operator and embodying it in the computer program, thereby controlling the process of design, planning and manufacture (Gill, 1994). Human-centred flexibility should pave the way to efficient machining where basic design should be derived from the study of human performance in machining.

Machine-centred flexibility is in general undesirable unless very careful rules are built into design and training. Errors may be induced by flexibility of systems due to destruction of the psychological coupling between information and control resulting from alteration or re-configuration of controls and displays. It is still believed that "in the era of advanced manufacturing high-calibre technicians are not replaceable especially those with considerable knowledge of metal cutting methods, cutting speeds and feeds, work-holding and tool setting techniques and those who are familiar with the control systems and programming for numerical control" (Gibbs, 1984).

The quality of conventional machine tools varies considerably, but quality work is produced by the skill of the operators who get to know their machines and make allowances for their failings (Gibbs, 1984). During the production of a component a skilled worker can, for example, compensate for leadscrew backlash, slide friction, lack of power, and so on while spindle speeds, feed rates and tooling arrangements are varied to suit the purpose. Varying the conditions is limited with a numerically controlled machine tool and making changes is inconvenient. Conditions have to be determined at the time the program is produced and the machine set.

Skill (Gill, 1994) is a combination of traditional and technological skill which is generally associated with a specific technology and production process. A skilled machinist operating a conventional machine makes decisions which influence the resulting physical activity where necessary actions are taken almost without thinking (Gibbs, 1984). The effective transfer of skill or knowledge can only take place when the person or group owning the skill or knowledge is also transferred to a similar working or social environment. What is transferable is the content and explicit descriptions of the objective part of the describable knowledge, but not the objective knowledge itself. The tacit dimension (experiential knowledge and personal knowledge) of core competences can only be transferred through the exchange and flow of practitioners and expertise.

Therefore, transfer of skill between skilled and unskilled operators in turning operations, by and large, remains a slow and inefficient process. Collective views on specific particular tasks both by skilled and unskilled operators could be used to determine any shortcomings experienced by unskilled operators compared with skilled operators. It is in the interest of this research that emphasis is given to human skills and mismatches during actual machining operations producing components by the use of conventional machines.

1.5. The Purpose to be Achieved

The long-term goal of this research is to understand the fundamental elements of skill and the experiential knowledge of operators in conventional machining operations, and to understand the difficulties in extracting this experiential knowledge. Eventually this would enable the build-up of expert knowledge inside a computer for machining although this is beyond the scope of the present research. Such research is of both applied and theoretical interest.

From a practical point of view, an understanding of the elements of expertise in conventional machining and an understanding of the difficulties of attaining an expert level will provide the principles for more effective and more efficient training (and re-training) of machinists for conventional machining operations. In addition, it is expected that this information could be used in the development of machine tools with human-centred features based on human psychological, technical and physical characteristics.

Specifically, the overall objective of the research is to formally establish the relationships between human skill, human performance and the preferred level of automation. This is seen as a useful contribution in determining the appropriate mix of human skills for modern manufacturing enterprises.

Therefore, with respect to manual turning operations, the objectives for this research are as follows :

i) To establish the relationships between mismatches and specific human characteristics i.e. skill, self-confidence, level of trust, work experience and age.

ii) To establish the relationships between self-confidence and specific human characteristics i.e. skill, level of trust, work experience and age.

iii) To establish the relationships between level of trust and human characteristics i.e. skill, work experience and age.

iv) To establish the relationships between the mismatches and preferred levels of automation.

v) To determine the preferred levels of automation (PLA) on the basis of relationships between PLA and specific human characteristics i.e. skill, self-confidence, level of trust, work experience and age.

vi) To establish the level of automation preferred for each category of human functions i.e selection, setting-up and inspection.

Although the general features and characteristics of machining are documented there are very few empirical studies of machining operations carried out to determine the level of automation required or essential for a particular scenario. Therefore, this research was designed to describe the performance of operators in terms of mismatches on conventional machining operations because these were considered as the starting point for advanced manufacturing.

The research was not designed to disprove claims about the absolute benefits of contemporary machining over conventional machining operations, but to describe how the former paradigm could be exploited for more refined used in automation.

1.6. The Hypotheses and Model

The model shown in Figure 1.5 depicts the relationships between variables and these are formally defined below in a set of eighteen hypotheses labelled H1 - H18.

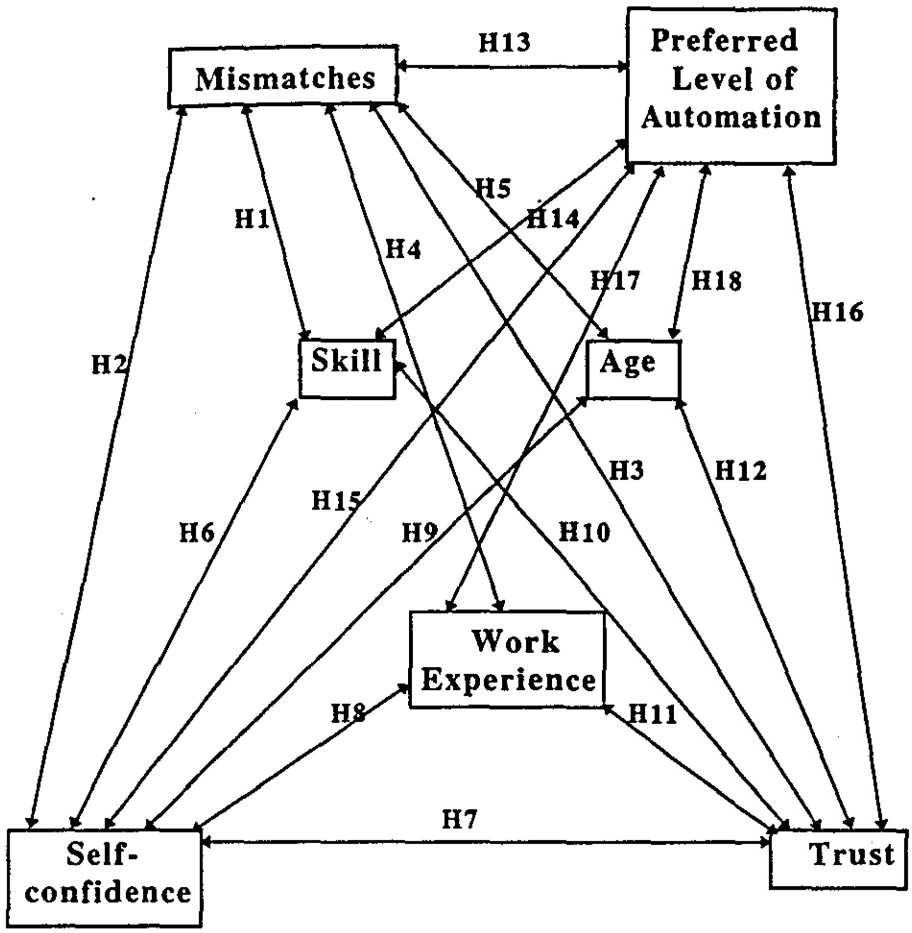


Figure 1.5 A model of hypotheses depicting the relationships between variables.

These hypotheses have been developed after an extensive review of literature on human problems in machining operations (Chapter Two). The model resulting from these hypotheses is a path model linking the eighteen latent variables into a path diagram. The construction of these hypotheses is discussed in greater detail in Chapter Three.

1.6.1. Mismatches

H1 : The higher the skill level of operators, the fewer mismatches are committed.

H_0 : There is no relationship between skill levels and mismatches.

H_1 : There is a relationship between skill levels and mismatches.

H2 : Operators having high self-confidence commit less mismatches.

H_0 : There is no relationship between self-confidence and mismatches.

H_1 : There is a relationship between self-confidence and mismatches.

H3 : Operators having a high level of trust commit less mismatches.

H_0 : There is no relationship between level of trust and mismatches.

H_1 : There is a relationship between level of trust and mismatches.

H4 : The longer the working experience, the fewer mismatches committed.

H_0 : There is no relationship between working experience and mismatches.

H_1 : There is a relationship between working experience and mismatches.

H5 : The higher the age of operators, the fewer mismatches committed.

H_0 : There is a no relationship between operators' age and mismatches committed.

H_1 : There is a relationship between operators' age and mismatches committed.

1.6.2. Self-confidence.

H6 : The higher the skill level of operators, the higher their self-confidence.

H_0 : There is no relationship between skill levels and self-confidence.

H_1 : There is a relationship between skill levels and self-confidence.

H7 : The higher the self-confidence, the higher the level of trust.

H_0 : There is no relationship between self-confidence and trust.

H_1 : There is a relationship between self-confidence and trust.

H8 : The longer the working experience, the higher the self-confidence.

H_0 : There is no relationship between self-confidence and working experience.

H_1 : There is a relationship between self-confidence and working experience.

H9 : The higher the age of operators, the higher their self-confidence.

H_0 : There is no relationship between self-confidence and age.

H_1 : There is a relationship between self-confidence and age.

1.6.3. Level of trust

H10 : The higher the skill levels of operators, the higher the level of trust.

H_0 : There is no relationship between skill levels and the levels of trust.

H_1 : There is a relationship between skill levels and the levels of trust.

H11 : Operators having longer working experience show higher levels of trust.

H_0 : There is no relationship between working experience and higher levels of trust.

H_1 : There is a relationship between working experience and higher levels of trust.

H12 : The higher the age of the operators, the higher the levels of trust.

H_0 : There is a no relationship between operators' age and levels of trust.

H_1 : There is a relationship between operators' age and levels of trust.

1.6.4. Preferred levels of automation

H13 : Operators who prefer higher level of automation commit less mismatches.

H_0 : There is no relationship between a preference for higher level of automation and mismatches.

H_1 : There is a relationship between a preference for higher level of automation and mismatches.

H14 : Skilled operators prefer lower levels of automation.

H_0 : There is no relationship between skill and a preference for lower levels of automation.

H_1 : There is a relationship between skill and a preference for lower levels of automation.

H15 : Operators having high self-confidence prefer lower levels of automation.

H_0 : There is no relationship between self-confidence and a preference for lower levels of automation.

H_1 : There is a relationship between self-confidence and a preference for lower levels of automation.

H16 : Operators having higher levels of trust prefer lower levels of automation.

H_0 : There is no relationship between level of trust and a preference for lower levels of automation.

H_1 : There is a relationship between level of trust and a preference for lower levels of automation.

H17 : Operators having longer working experience prefer lower levels of automation.

H_0 : There is no relationship between working experience and a preference for lower levels of automation.

H_1 : There is a relationship between working experience and a preference for lower levels of automation.

H18 : Higher age operators prefer lower levels of automation.

H_0 : There is no relationship between age and a preference for lower levels of automation.

H_1 : There is a relationship between age and a preference for lower levels of automation.

1.7. Organisation of the Thesis

The organisation of the thesis is as below :

Chapter Two reviews the literature concerning errors and mismatches, how and why they occur and confirms the model (Figure 1.3) on their relationships with machining operations.

Chapter Three describes the formulation of hypotheses derived from primary and secondary sources. Development of hypotheses covered several areas of interest namely mismatches, skill, age, working experience, level of trust and self-confidence.

Chapter Four provides a review of procedures. Based on the literature, various techniques were considered and evaluated. An experimental technique was chosen for part of the study on mismatches while a questionnaire survey was carried out on mismatches and other variables including skill, age, working experience, level of trust and self-confidence. Limitations and advantages of all the techniques are also discussed.

Chapter Five describes the methodology and data gathering techniques. Detailed explanation of the techniques used are discussed with some elaboration on difficulties and limitations encountered.

Chapter Six describes the analysis of data and empirical results. Results are shown to correspond to the objectives stated earlier in the thesis.

Chapter Seven elaborates findings and compares them with previous studies. It extends discussion on the preferred levels of automation in machining and provides some generalisation arising from the study.

Chapter Eight summarizes the research, recommends uses for the results, provides indications of areas that would benefit from further work and the conclusions of research.

1.8. Conclusion

This introductory chapter has provided an overview of the research. A justification for the research has been presented and suitable models suggested. Some elaboration on the focussed area provides strong evidence of the importance of the research.

The statements of hypotheses and the models provide a direction for the research. The review of literature presented in next chapter highlights supporting evidence from previous research, establishes the theoretical framework and provides a justification for the model proposed.

CHAPTER 2

LITERATURE REVIEW

2.1. Introduction

An extensive review of the literature has shown that mismatches have been investigated in various disciplines but rarely in manufacturing. Generally, mismatches have been analysed in the study of compatibility between humans and the systems and the environments within which they work. Understandably, mismatches provide an extra dimension in investigating issues involving human and other physical components. As far as machining performance is concerned, investigations have been from various perspectives including psychological, mathematical, manufacturing software and hardware and decision-making.

The literature review is organised into four main sections :

i) Human performance.
ii) Operators and machining operations
iii) Manual and automated systems.
iv) Initiatives in manufacturing.

2.2. Human Performance.

Studies on human performance tend to be inclined to either technological or organisational aspects. Industrial psychologists have long investigated this area from an organisational point of view with their interests including employee participation, teamwork, job attitudes and job design as activities that have an effect on human performance (Chaney, 1969), (Morrissette et al, 1975), (Baker and Salas, 1992), (Driskell and Salas, 1992). Various human performance problems (INPD, 1985 quoted by Reason, 1990) identified were:

Deficient procedures or documentation	43 %
Lack of knowledge and training	18 %
Failure to follow procedure	16 %
Deficient planning and scheduling	10 %
Miscommunication	6 %
Deficient supervision	3 %
Policy problems	2 %
Others	2 %

Research on human performance may be considered a classic area as far as human factors or ergonomics is concerned because numerous papers involving various disciplines such as physiology, psychology and biology have been published. However, there has been far less research work carried out in the area of human performance related to machine tools which should be the basis of understanding about human-machine interfaces for CNC machines and flexible manufacturing cells.

2.2.1. Variability in human performance

Selection (cognitive), setting-up (psychomotor) and inspection (perceptual-motor) are typical of many tasks and this is certainly true of machining operations. Every operator is bound to employ these mental activities in addition to physical activities in order to execute jobs. Physical activities may lead to a wide range of health, safety and welfare problems but these are beyond the scope of this thesis.

According to Salvendy (1983), mental activities and the performance of tasks depend heavily upon cognitive processes and functions. Three information-processing stages identified were perception, decision making and response control. It has also been shown that effective design and operation of manufacturing systems is influenced by human performance capabilities which include variability in work performance, information processing, task pacing and job satisfaction. Variations were the result of three general classes of operators' characteristics i.e. experience and training, enduring mental and physical characteristics influenced by motivation, illness, stress, alcohol, working hours, physical, social and the psychological work environment. Task characteristics (i.e. equipment, defects, malfunctions, methods) could also influence variability in human performance.

2.2.2. Mismatches

Mismatches have been the focus of considerable research and have been investigated in areas inclined towards the psychological and sociological disciplines.

In the psychological discipline, distinct self-regulatory systems (Higgins et al, 1994), dysfunctional mismatches between different control dimensions (Evans et al, 1993), gesture-speech mismatches in child development (Goldin-Meadow et al, 1993), human mental state matches or mismatches the state of the world (Hadwin and Perner, 1991), adjustment to mismatches between person and environment (West and Rushton, 1989), mismatch between task and current unaided performance level (developmental psychology) (Todman and McBeth,1994) and the match and mismatch of teachers and students in early child development and care (Saracho 1990) have been investigated.

In sociology and social economics, various areas covered include labour market mismatches (Hart, 1990)(Looney, 1992), supply and demand mismatches in training (de Moura Castro and de Andrade, 1990), mismatches between conflict and expectations (Mortland and Egan, 1987) and overeducation and skill mismatches (Halaby, 1994).

In new technology, the down swing of the world economy resulting from mismatch of a new technological style was investigated (Tylecote, 1995). In human organisation, skill mismatches resulting from structural unemployment have been investigated (Drori and Gayle, 1990) while in organisational behaviour, a growing mismatch was observed between an occupational niche and perspective workers (Eichar et al, 1991). A survey on the matching of high-performance organisations with technology and management strategies established that organisational success depended on the degree of integration that could create different demands on management practices (Majchzak and Paris, 1995).

The varied areas of research briefly outlined above demonstrate that the mismatch approach is one that has been widely used in many disciplines. All of these examples illustrate the central aspect of the mismatch approach where a pair of characteristics are investigated to establish the differences or unequalness between them.

In manufacturing, as far as work is concerned, alienation and limitations of output were considered the prime effects of the concept (of man-machine relationships being part of the content of the job), while mismatches between equipment and its users was identified merely as a less well-recognised effect (Corlett, 1980). This provides the reason why the study of mismatches in manufacturing has been lacking in comparison to other disciplines even though the term misfits or mismatches has been widely used particularly in human factors engineering.

Unavoidably, humans suffer from mismatches because humans are dynamic homo-sapiens that do not always strive for change and improvement. However, mismatches are more associated with human mental perceptions and thus involve the brain, an organ for which we have an incomplete understanding of its evolution, characteristics and capabilities. The study reported in this thesis stresses the results and consequences of mismatches in machining environments that has clearly been absent from previous research.

2.2.3. The occurrence of mismatches

Mismatches are generated by human operators but the mechanism depends on variability in human performance (Rasmussen, 1986). In machining operations, skill is critical in meeting standards in production. Bohle et al (1994) pointed out that sensory perception did not contribute to skill demands while Salvendy (1983) showed that fundamental cognitive processes and functions contributed to information-processing, memory and decision making capabilities in human operators.

The occurrence of mismatches in executing tasks by operators depends on information received from the environment and sensory perceptions. According to Bohle et al, (1994), two types of sensory perceptions of interest are objective and subjective perceptions.

Objective perceptions are the understanding and knowledge that would allow objectifying actions to take place i.e. rational thinking, using memory, isolating single senses, obstructing emotions, using scientific and theoretical knowledge and highly factual unemotional interactions.

On the other hand subjective perceptions are the understanding and knowledge that would allow subjectifying actions to take place i.e. associative, intuitive thinking, memory as a process, complex sensory perceptions, emotions served to gain knowledge, experiential knowledge, feelings and subjective perceptions as part of working and dialogically-exploring procedures.

In order to execute specific tasks, objectifying actions should take place. Hence, subjective perception is largely replaced by objective perceptions. Based on this perception, information is registered before decision making processes take place.

Subjective factors and skilled work influence the process of registering information. Skilled work depends on the operator's responsibility, individual initiative and creativity while subjective factors depend on emotions, sensations, impression etc. There are positive and negative aspects to the subjective factors. Positively, there are significant advantages for individual motivation and subjective satisfaction. Negatively, the subjective factors are disruptive, the cause of errors and hence the cause of mismatches, for example :

a) correct dealing with technical working material
b) efficient work or task
c) goal oriented mastering of working demand,

Figure 2.1 shows a flow chart of the propagation of mismatches through sensory perceptions based on the work of Salvendy (1983) and Bohle et al (1994).

Thus, determination of the frequency of mismatches in machining operations should reflect the negative aspects in subjective factors which influence the process of registering information.

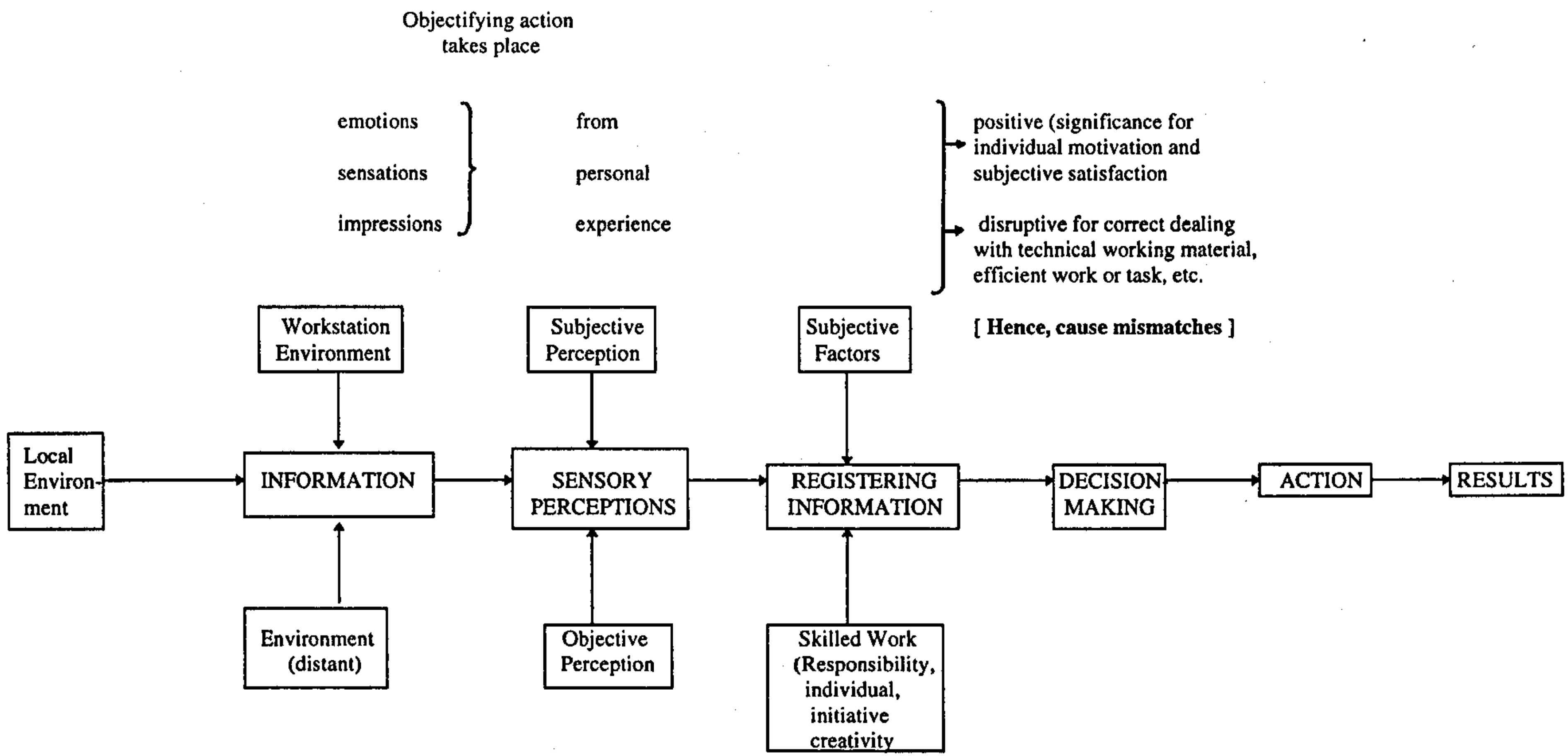


Figure 2.1 The Evolution of Mismatches
(Source : Adapted from Salvendy (1983)
and Bohle et al, (1994)

In another development, it was suggested by Reason (1990) that concurrent processing by the knowledge base and working memory may take place in human problem solving according to the model as shown in Figure 2.2. Rapid information retrieval, similarity-matching and frequency-gambling take place in a knowledge base domain. Meanwhile, evaluation of solutions takes place in the working memory domain.

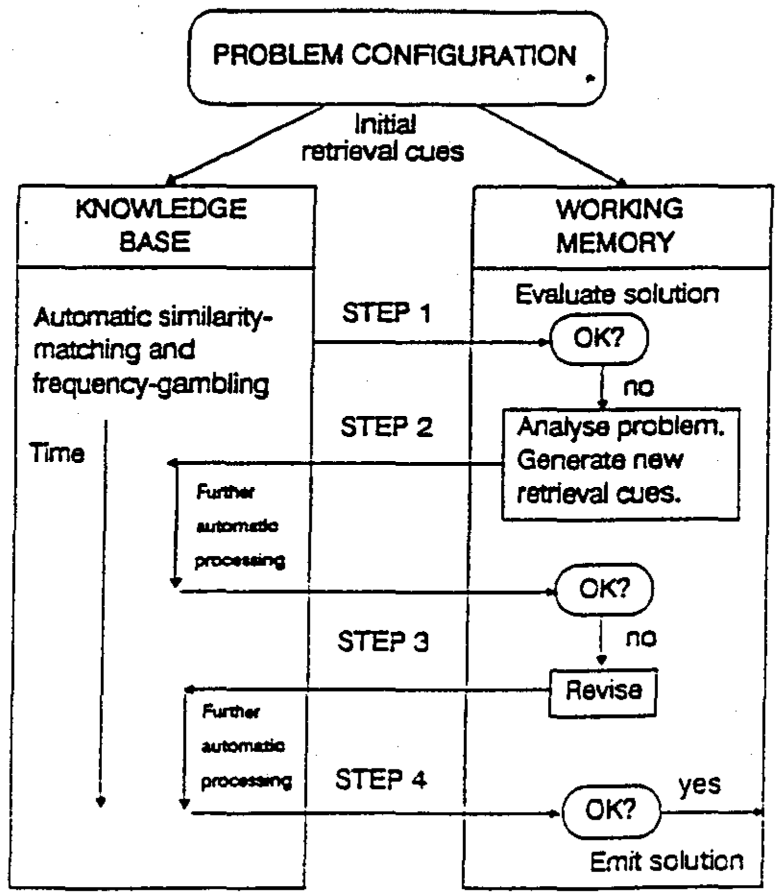


Figure 2.2 Concurrent processing during problem solving

(Source : Reason, 1990)

An interaction process exists that causes a flow of information from the knowledge base to working memory and vice versa while subsequent decisions are made in working memory. The knowledge base, which has the advantage of a large memory, is responsible for gathering information (corresponds to "information" in Figure 2.1). Working memory plays a role in evaluating (corresponds to "sensory perceptions" in Figure 2.1), analysing and revising problems (corresponds to "registering information" in Figure 2.1) before emitting solutions and making decisions. Hence, these suggestions support the model of the evolution of mismatches in Figure 2.1.

The flow chart modified from Bohle et al (1994), Salvendy (1983) and Rasmussen (1986) shows that mismatches are derived from information processes and not from human decision-making processes. Justification of this has not been established, and hence there is a gap in this area of research. Meanwhile, Reason (1990) has shown that mismatches occur at the decision-making stage of task performance.

2.2.4. Error Occurrence

Errors occur at every level of human and machine functions. They persist throughout from simple machines and processes right through to sophisticated production equipment and processes. Operational and machine errors are unavoidable. Recently the analysis of errors has been investigated in relation to various aspects of manufacturing. Continuation of these investigations is essential in order to fully understand the problems and to devise new methodologies that reduce the occurrence of errors.

The human factors analysis of an automated process plant (Hockey and Maule, 1995) revealed that operators often assumed manual control over the production schedule, overriding the process computer. This clearly shows the inconsistencies that can occur between actual and intended use and the need to accommodate options in modified designs. Suggestions given were that unscheduled manual interventions (UMIs) be controlled or prevented (by further training, more secure programming, monitoring of individual process records, etc.), or they might be supported (e.g. by the use of appropriate decision-aiding tools). Prevention and control were meant to reduce the risk of accidents or serious production errors while UMI support was to allow operators to contribute effectively to the maintenance of production goals.

Error avoidance is one of three broad classes of solutions for machine tool errors (the other two being error compensation and error correction) (Charles Stark Draper Laboratory, 1984). This is the easiest and least costly method of eliminating human or operational errors. It usually consists of maintaining good shop and machining practices, maintenance disciplines, and an awareness of how fixture design, poor tool setting, or other actions can affect machine and part accuracy. Error avoidance could lead to significant improvements in part accuracy at very little expense in time or effort. The most common errors in Flexible Manufacturing Systems (FMS) occurred at the interfaces to humans, with misalignment and variation in preset tools or missetting of the tools being the most common problems encountered.

In automated assembly, handling errors are one of the new problems created by advanced technology in manufacturing industries. O' Connor et al (1993) analysed subjects and the classification of errors for the development of error management expert systems. The system was intended to assist designers and provide intelligent control systems capable of detecting imminent errors, taking corrective actions and/or recovery from them. Operational and hardware errors were likely to be minimized or reduced by the system. The study attempted to quantify handling errors for the improvement of assembly tasks in manufacturing. Therefore, there is a need for research in the area of human performance to include error analysis for the purpose of quantification and understanding.

Faults and errors committed by humans have also been investigated in aviation (Gerbert and Kemmler, 1986) where studies highlighted the determinants and background human variables related to incidents and accidents. Another study (O'Hare et al, 1994) investigated the applicability of the information processing approach to human failure in aircraft cockpits. However, both studies failed to establish relationships between errors and basic human characteristics.

Fatigue, strain and boredom are inherent human characteristics of importance to both conventional and automated processes. However, the two types of process can be differentiated by the degree of severity and the cause of occurrences. For automatic equipment (Welford, 1960) fatigue and strain are less likely to arise from excessive physical demands and are most likely to arise from the need for frequent rapid decision-making and excessive information processing. Boredom might result from repetitive or uneventful tasks that consequently lead to mismatches in task performance.

2.2.5. Conclusion

Human variability is a phenomenon that produces physical outcomes such as human errors, mismatches, slips and mistakes. Understanding of human variability and its quantification are sought for application in the development of technology in a human-centred fashion. Aspects of human variability in machining tasks need investigation because this has not been fully covered in the literature.

2.3. Operators and Machining Operations

2.3.1. The making of expert machinists

Expert machinists are knowledgable operators who have gathered tremendous amounts of knowledge from a long experience of practical machining. Much of the knowledge concerning the nature of materials, tools, cutting conditions, optimal set-up for machining, etc. could be exploited and transferred to a computer-based expert system (Inoue, 1986). However, expert systems do not provide the relationships between machining operations and human characteristics that are essential in developing a better understanding of man-machine interaction within an environment of continuous improvement.

Buchanan and Bessant (1985) demonstrated that process operators required considerable skill, knowledge, experience and training to deal with process faults, cope with contingencies, and to control the process effectively. Effective production depended more on human presence and ability than in the simpler case of batch production because of the limitations of computer control and the high cost of error. However, the study did not quantify task performance or the probability of achieving a minimum number of operating errors and mismatches.

2.3.2. Approaches to the problem

One way of investigating problems is by studying the functions of humans and those of machines (Price, 1985). The allocation of function is normally associated with human skills where it is suggested that the characteristics of human skills should be used to aid the solution of allocation of function problems (Whitfield, 1967). It should also be acknowledged that human performance was found to be better compared to machines because of the human decision-making capability. Humans are also better able to maintain consistency in classifying items as acceptable or rejects in inspection tasks even though machines have proven capable of locating most faults (Drury and Sinclair, 1983).

To minimise human errors and to maximise quality in production requires a plan and extensive study of the causes and control of errors. Hierarchical task analysis, human error analysis and presentation guidelines have been used to develop a set of comprehensive operating procedures and checklists (Livingstone et al, 1992). The method was a highly effective and economical means of reducing errors in routine tasks. The recovery of critical errors was prompt and enabled the checklist to be used as an on-line job aid.

Various techniques have been used to achieve favourable designs of machines taking into account ergonomic considerations. Analysing and optimising a CNC grinding machine in its design phase has been carried out using videosomatographic analysis (Schindhelm et. al, 1992). Alternative designs were proposed for the weak points revealed during the analysis of the operator's activities on the machine. The activities were :

i) adjusting the headstock where direct access to it was necessary. A handle was suggested to avoid tilting of headstock while being shifted.
ii) changing the surface planer so the job could be done in an upright stance.
iii) changing the working component. A manual lever was re-designed to enable the clamping of the working component.

2.3.3. Applications

Frederick (1983) reviewed application and operation experience within an automated manufacturing system for drilling and found that operator's work input (task assignment) should be balanced with operator's work output (responsibility). This was to reduce the problems of work monotony, mental strain, high absenteeism and high personnel turnover through consideration of effectiveness and changeability of equipment and the need for social contact among operators. However, the study did not cover aspects of incompatibility between human tasks and those required by a particular system.

An investigation on the impact of menu hierarchy on performance effectiveness revealed that performance time and errors were correlated with the hierarchy level of data structures. Personnel selection tests had been found able to improve the effectiveness of the task (Seppala and Salvendy, 1985). It has also been found that the skill requirements of FMS jobs were greater than the skill requirements of both stand-alone conventional and NC equipment as well as achieving equally high levels of satisfaction and motivation (Adler, 1991). The study revealed problems of incompatibility between operators and systems and human characteristics.

Human error in monitoring and diagnosis have been more widely covered in ship navigation (Gardenier, 1981), aviation (Thompson, 1981), (Ephrath and Young, 1981), (Wickens and Kessel, 1981) and nuclear power plants (Sheridan,1981) compared to that in manufacturing plants. An analysis of human error known as DREAMS (Dynamics Reliability technique for Error Assessment in Man-Machine Systems) has been developed with the aim of identifying the origin of human errors in the dynamic interaction of the operator and a plant control system (Cacciabue, Carpignano and Vivalda, 1993). Similar studies are not easy to find in machining operations even though in manufacturing "error studies have been more predominant in computer utilisation such as human-computer interaction which involved computer programs controls, displays and training" (Bond, 1981) (Brooke, 1981).

2.3.4. Conclusion

Operators and operations are inseparable and these contribute to human variability. Manually-operated machines need specific expertise and this demands time, cost and the development of familiarity through working experience. These observations form an important starting point for the current investigations, and lead directly to the development of the methodology used in this research.

2.4. Manual and Automated Systems

2.4.1. Levels of automation

The concept of automation is rather vague and obscure even though the term can be defined as activities which replace human physical activity by other (usually mechanical) means. It is clear that human mental work has been progressively substituted by machine activity (Rosenbrock, 1985). However, it has been realised that the nature of the human role in tasks changes with the level of automation and has implications for both the system (performance measures) and the human (stress measures)(Drury and Goonetilleke, 1992). Drakeford and Hardy (1994) established that automation was not necessarily the most effective vehicle for improvement based on a study of a particular manufacturing process.

Refining the concept of automation has been suggested as a means of allowing better understanding of the development of production technology vis-a-vis automation (Coombs, 1984). Bright (1956) first suggested a classification scheme (Table 2.1) that described seventeen levels of automation where the lowest level (level 1) involved the use of the hand and the highest level includes anticipative and adaptive machines. The levels are related to the source of control (human, machine pre-determined or environmental) and the machine response (variable, fixed, signal or action).

An alternative mechanisation profile (shown in Figure 2.3.) was suggested by Bell (1972). The profile takes the form of a matrix relating loading, unloading and transfer tasks to hand tools, human powered machines and non-human powered machines in the context of levels of automatic control. Sheridan (1994) suggested a scale of degrees of automation as shown in Table 2.2.

Levels or degrees of automation have been suggested by several authors but the studies are severely lacking in respect of users' relationships and responses to particular levels that might provide significant contributions to design or training.

"Systems do not work unless people make them work" (Rothwell, 1987). This statement supports the notion of reducing the mismatches to allow for more effective utilisation of machines by individual operators as work depends on people.

Initiating Control Source	Type of Machine Response		Power Source	Level Number	Level of Mechanisation
From a variable in the environment	Responds with action	Modifies own action over a wide range of variation	Mechanical (Non-manual)	17	Anticipates action required and adjusts to provide it
				16	Corrects performance while operating
				15	Corrects performance after operating
		Selects from a limited range of possible pre-fixed actions		14	Identifies and selects appropriate set of actions
				13	Segregates or rejects according to measurement
				12	Changes speed, position, direction according to measurement signal
	Responds with signal			11	Records performance
				10	Signals pre-selected values of measurement (includes error detection)
				9	Measures characteristic of work
From a control mechanism that directs a predetermined pattern of action	Fixed within the machine			8	Actuated by introduction of work piece or material
				7	Power-tool system, remote controlled
				6	Power tool, program control (sequence of fixed functions)
				5	Power tool, fixed cycle (single function)
From man	variable			4	Power tool, hand control
				3	Powered hand tool
			Manual	2	Hand Tool
				1	Hand

Table 2.1. Bright's mechanisation profile
Source : Bright (1956)

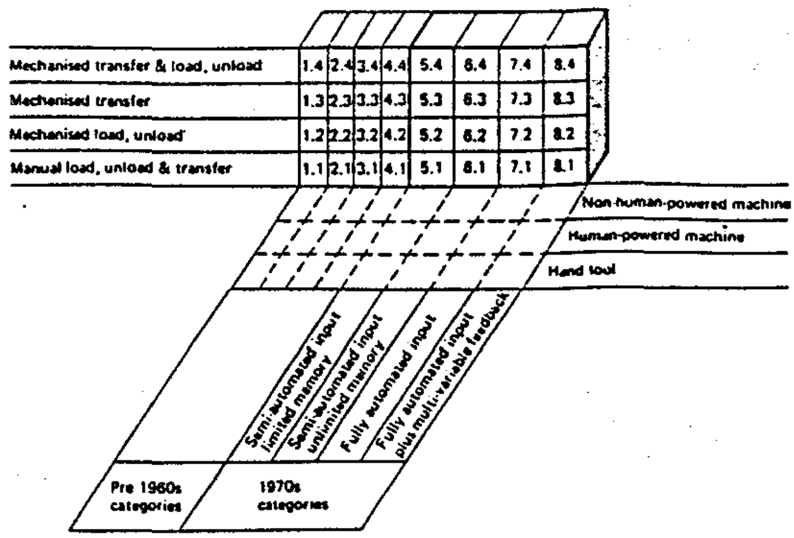


Figure 2.3 Bell's mechanisation profile

(Source : Bell, 1972)

1. The computer offers no assistance, human must do it all
2. The computer offers a complete set of action alternatives, and
3. narrows the selection down to a few, or
4. suggests one, and
5. executes that suggestion if the human approves, or
6. allows the human a restricted time to veto before automatic execution, or
7. executes automatically, then necessarily informs the human, or
8. informs him after execution only if he asks, or
9. informs him after execution if it, the computer, decides to
10. The computer decides everything and acts autonomously, ignoring the human.

Table 2.2. A Scale of Degrees of Automation

(Source : Sheridan, 1994)

Matching operators' preferences and capabilities to the appropriate level of automation of systems should optimise operator-machine relationships. Although considerable effort has been put into optimising human-machine interactions, this has not resulted in formal methods for determining the particular levels of automation appropriate for specific groups of operators.

2.4.2. Human and machine perspectives

Tasks and the capacity of performing them can be viewed from either the human or machine perspective. With reference to Table 2.3 people and machines have mutual differences when viewed from contra perspectives (Norman,1993). From a human perspective, people are intelligent and flexible, but in contrast machines are dumb, rigid, insensitive to change, unimaginative and work only on programmable decisions. However, from a machine perspective, people are vague, disorganised, distractable, emotional and illogical whilst the reverse is true of machines.

Various areas of interaction between human and machines, such as machining tasks and automation could be re-analysed to obtain measures of compatibility between the human and machine components. Similar treatment should apply to generalisations about advantages and disadvantages of automatic man-machine systems as suggested by Wiener and Curry (1980) and shown in Table 2.4.

Selecting the task may be one human contribution to machining inefficiency. "The selection of a correct sequence of operations, together with efficient cutting speeds and feeds, tooling and work holding, and the ability to express these requirements in the correct format are of paramount importance" (Gibbs, 1984). Selection of tasks could very well be performed by machines.

But it has been argued that production which incorporates either total automation or merely one or two numerically controlled machines positioned among traditional machines might result in a decline in practical skill level requirements and reduced efficiency on the shop floor. Yet, in the study, no reference was made to an analysis of human mismatches in machining operations.

Human Perspective		Machine Perspective	
People	Machine	People	Machine
Creative	Dumb	Vague	Precise
Compliant	Rigid	Disorganised	Orderly
Attentive to change	Insensitive to change	Distractible	Undistractible
Resourceful	Unimaginative	Emotional	Unemotional
Decision are flexible because they are based upon qualitative as well as quantitative assessment, modified by the special circumstances and context.	Decisions are consistent because they are based upon quantitative evaluation of numerically specified, context-free variables.	Illogical	Logical

Table 2.3. Comparisons between human and machine perspectives

(Source : Norman, 1993)

The human workforce may be placed at the focal point of production, manufacturing, quality, productivity, etc because it is one particular resource that is of prime importance to the manufacturing sector. Analysis of mismatches in manual machining operations can make a significant contribution to the successful implementation of this strategy.

Total replacement of workers and their tasks by robots should be avoided because human involvement and contributions are needed to optimise manufacturing prosperity. Similarly, automatable work should be re-analysed to achieve a fair distribution between human and machine on the understanding that the human and the machine are two separate entities each with their own particular attributes.

Advantages	Disadvantages	Questionable	Unknown
Increased capacity and productivity	Seen as dehumanizing	Overall workload reduced or increased	Capital acquisation costs
Reduction of manual workload and fatigue	Low alertness of operators	Total operational cost increased or decreased	Use of common hardware
Relief from routine operations	Systems are fault intolerant-may lead to larger errors	Training requirements increased or decreased	Maintenance costs
Relief from small errors	Silent failures	Reduction in crew size	Extent of redundancy necessary and desirable
More precise handling of routine operations	Lower proficiency of operators in manual situation		Long-range safety implications
Economic utilization of machines	Over-reliance and complacency		Long-range effects on operators and other personnel
Damping of individual differences	False alarms		Long-range implications for collective bargaining
	Automation-induced failures		Implications for civil liability
	Increase in mental workload		

Table 2.4. Generalisations and advantages and disadvantages of automatic man-machine systems.
(Source : Wiener and Curry (1980))

In inspection processes, attempts have been made to improve manual inspection performance to avoid the non-feasibility and cost ineffectiveness of automated inspection (Kopardekar and Mital, 1992). Understanding factors that could influence tasks before allocating functions to either humans or machines is considered from both human and machine perspectives and human preference may take precedence over technological alternatives. Shackel (1967) initiated this argument in recommending total system participation for dealing with human factors problems in advanced technological systems.

A Japanese contribution to this general field is evident in Kaizen, a technique for continuous improvement in manufacturing. Kaizen refers to finding and eliminating work or elements of work that are considered unnecessary for production (Singh and Falkenburg, 1994). Kaizen differs from the current study as it covers a wide scope of work and processes while the current study is specifically concerned with human mismatches with the aim of reducing incompatible, inappropriate, unsuitable or improper actions detrimental to production.

One method to describe and analyse causes of errors by human operators uses frames and a special kind of modal logic and utilises operators' characteristics and the situation in which an error was made. The method enables every error to reveal its intrinsic sources which can be used for making recommendations concerning their elimination (Yemelyanor and Kotib, 1992). A study revealed that root causes (i.e. external events, excessive task demands, intrinsic human variability, human inefficiency, incapacitated, organisation deficiencies) and coupling mechanisms (i.e. information, equipment, intrinsic human capabilities, skill organisation) result in human dependent failures an understanding of which could effectively help to reduce human errors in general (Hollywell, 1993).

2.4.3. Comparison between manual and automated systems.

Modernization that commonly leads to automation aims to improve the quality of the work environment for the operators. Repetitive strain injuries (RSI) to the neck, shoulder, arms, back and hand regions persisted even though it was expected that automation would generate a noticeable decrease in such problems. This was clearly indicated by the injury statistics of 110 employees during partial automation (1986-87) and full automation (1987-90) (Wands and Yassi, 1993).

Specific problems involving human operators and particular systems could be observed using comparative studies of manual and automatic systems. Previous studies have highlighted various issues inherent to systems' operations (Mital, 1988), (Wilson and Rutherford, 1987). In manufacturing, decision making encompasses issues of whether to automate, not to automate or what to automate. There are uncertainties in terms of what level of automation is required for particular machinery or systems that is acceptable to human operators.

It is anticipated that in future, decision making might cover a broad spectrum of choices which include the choice of factories such as : robotics-based, computer-integrated, fully automated or flexible manufacturing (Swyt, 1986). It has been pointed out that "over time the level of automation varies with capacity and expansion in the area of communications" (Chorafas, 1990) but no suggestion has been made for discrete levels of automation implementation. Determination of the possible levels of automation is not well-documented, particularly with regard to generalisation to achieve very much improved human-automation interaction.

It has been suggested that there is a need for an integrated model of computer-integrated manufacturing systems (CIMS) operation. This should "include the economic, human factors and technological data that can be used in the design and implementation of an appropriate level of automation for a given application which is essential to expand the range of application of the CIMS concept and to improve the economics of CIMS implementation" (Kramer, 1987). Levels of automation were mentioned rather arbitrarily which showed either levels of automation had not been established or a lack of commitment to particular levels of automation. Hence, the absence of support for the decision-making process. Furthermore, human factors issues where compatibility between cognitive responses (mismatches, skill, level of trust, self-confidence) and machining tasks were not investigated in this study.

The design of automated machinery may be considered as technology-based while in contrast the design of manual machines is based on the working-process (Bohnhoff and Henning, 1990). Automated machinery is produced from technological innovations aimed at exploiting human's (engineers and designers) technical ability while a manual machine is designed based on the essential working procedures inherent to produce specific components. Even though automated machinery is developed subsequent to a manual machine, the human's roles are being limited irrespective of human preferences.

The two types of design (technological and working-process based design) should be complementary and lead to an optimal design for economic advantage. The relationships between variable human characteristics (skill, work experience, age, self-confidence, level of trust and preferrence for automation) established for manual turning operations should provide the basis to meet the demand of both the technical processes and the process of human work.

Very little research has been conducted that directly compares activities in machining operations across different machining systems (such as conventional and automated machines) although one would expect to see substantial system-dependent differences. Designs combining aspects of manual and automated systems have been developed by upgrading existing manual or conventional machines. This may permit the production of more complex components but selection of the level of automation has typically not been based on a psychological approach but has been based on the technical capacities of production machines (Gates Machinery International, 1995). However, several commentaries have been written comparing conventional and automated systems (Ekkers et al, 1977), (Mattila and Kavinitty, 1993), (Hazlehurst et al, 1969), (Lewis and Deivanayagam, 1983). Comparisons of particular areas include the following aspects :

2.4.3.1. Control tasks

In considering control tasks Ekkers et al (1979) concluded that :

a) work load and stress have a positive effect on the subjective health of the operators.
b) complex systems and a relatively slow process combined with a large amount of indirect control, gives rise to low values for experienced stress and work load that are related to feelings of less good health.
c) subjective work load on the operator is an important variable, and is related to the system complexity and the task dimensions. It has a significant relationship to subjective health. It appears in the study that a positive relationship exits between subjective work load and with feelings of achievement in the work.
d) An analysis on the level of the system and not on that of the individual operator, can provide meaningful results with regard to the human aspects of man-machine systems.

The above study made comparisons of work load and stress among operators but mismatches, which identify incompatibility with work performance, were not investigated.

2.4.3.2. Occupational safety

Content, characteristics and occupational safety of jobs differ with the level of automation (Mattila and Kavinitty, 1993).

a) Job content requires more planning and information processing, while at the same time the central tasks e.g. fabrication and machine operation, remain essentially the same.
b) The characteristics of jobs with different levels of automation seemed

to differ, which were mostly positive from operator's point of view.

c) Job safety improves with higher levels of automation. For example, the work environment of CNC jobs is safer than that of manually operated machines. The study showed that although a higher level of automation improves safety, the role of devices becomes more critical.

Job content, characteristics and safety were compared but not related to issues of work performance.

2.4.3.3. Skill of machinists

A comparison of the skill of machinists on numerically-controlled and conventional machines (Hazlehurst, Bradbury and Corlett, 1969) concluded that :

a) the extent to which physical effort was diminished largely depended on the extent to which the machine was "automated".
b) NC involved some reduction in the demand for motor skills and the associated perceptual load related to precision and accuracy of movement.
c) NC involved an appreciable increase in the demand for perceptual skills associated with vigilance, machine monitoring and controls.
d) NC involved an appreciable increase in the demand for conceptual skill associated with the interpretation of symbolic information in the forms of drawings, planning instructions and calculations.
e) NC involved an appreciable reduction in the number of decisions an operator is required to make.

Clegg (1984) demonstrated divergent effects of new technology on the operator's job when working with CNC machine tools. Operators who were allocated jobs such as proving out and editing tapes, setting up tools and machines, reading technical drawings, making decisions about cutting properties and speeds for different metals, etc. were very positive about their jobs compared to those operators who had their jobs simplified by automation.

2.4.3.4. Robotization

A comparison between operator's work before and after robotization (Lewis and Deivanayagam, 1983) concluded the following :

a) There was a reduction in physical effort required of human operators.
b) Operators had to learn and acquire new skills needed to work with robotization.

However, the psychological aspects of human at work with robotization were not addressed.

2.4.3.5. Conclusion

The above studies highlight the differences between manual and automated systems, and generally show that automation is not the ultimate solution. The process of automation is by no means simple, and needs painstaking effort to achieve optimisation of the combined human and automation aspects. Analysis of manual operations (as in this research) is expected to provide the basis for a clearer understanding of the area of manual-automation as far as task performance is concerned.

2.4.4. Human attributes in manual and automated machining

"A working person is not comparable to a piece of equipment in use or a wordprocessor in operation. A working person is more than a labour factor, information and energy. He is a carrier of ethical and moral values, and has a historical patrimony. Thus, a working person cannot be replaced by machinery, even though machines can replace human resources which are employed" (Petrella, 1984). In an economic sense, the under-use of human ability would clearly be a loss (Rosenbrock, 1985). The necessity to hold human operators in high regard implies that an appropriate compromise between machine and operators is particularly important. However, in automation there has been a lack of ergonomics knowledge available while the current knowledge has not been widely used in system design (Shackel, 1967). It is observed that a similar situation prevails to this day although the problem is multi-dimensional and needs to cover many variables. Automation of machining has long been in existence but it should not be left in a "constant technology" condition because according to Venda et al (1992) a company with "constant technology" could quickly become uncompetitive.

Human contributions to machining are endless, and include adaptability, learning capability, preferences, trust and self-confidence. Humans may be adaptable (after training) and well-adjusted to machining operation requirements. They are capable of learning new things, as every second of exposure to a particular machine results in learning taking place with a consequent build-up of knowledge and experience. These enhance work performance. Preferences, trust and self-confidence result from these experiences.

Three human attributes related to the current study are discussed below :

2.4.4.1. Preference

Humans have preferences in situations or circumstances where there are choices. In machining, preferences occur to operators because there are types of machines, manual or automated, varieties of tools, various cutting parameters, etc. even though in most cases objective preferences predominate. However, a critical choice is the human preference for either manual or automated machining processes because preference should contribute in deciding the ultimate design features of machines.

Criteria are essential to establish preferences, and are important because they form the basis for making the right choices. In the author's opinion and supported by Goldstein (1971), preferences in machining should allow people to suit his or her own needs and capabilities. Perfect interaction between human and machines is the ultimate goal, but as this often beyond reach the satisfaction of personal preferences can be a satisfactory alternative.

Preferences in machining have not previously been studied in detail, but according to a study in the related area of the preferences for cyclic automation, it was discovered that a trade-off exists between performance and workload (Scallen et al, 1995). Results supported the findings that short cycles of automation were detrimental to performance in multi-task conditions. This work did not consider mismatches, trust and self-confidence of systems, but rather implied the following :

a) the duration of episodes of automation could have impacts on operator performance.
b) identification of micro-trade offs within tasks and macro trade-offs between tasks.

Scallen et al, (1995) also suggested that consideration of the identification of appropriate components in relation to automation or the lack of it was also required, since the change of status appeared to have direct effects on performance. Adaptive systems for provisions for a cycle between manual and automated control should also be evaluated.

2.4.4.2. Trust

In person to person relationships, "trust is a dynamic expectation which follows a certain developmental sequence as a relationship progresses. This developmental sequence is predictability, dependability and faith" (Rempel et al, 1985). More specifically in machining operations, the machine is a partner in machining interactions and there is a development of trust between operator and machine. It is expected that routine procedures do not fail, results are as predicted within reasonable allowances and actions yield the desired results.

Trust develops as the human-machine relationship progresses in a similar way to the development of human-human relationships. Even though relationships may be unilateral, it is critically important because production is at stake. If operators do not trust machines, output is reduced. Knowing the limited capability of a machine and realising his or her own shortcomings (through training) a compromise should prevail to meet production demands. Limitations vary between machines and depend on a number of factors such as the machine's age, technological capability and state of maintenance. Hence, operators' trust in a machine is vital to human-machine relationships and thus to production.

2.4.4.3. Self-confidence

Trust of machines alone does not fulfill the essential ingredients needed in the human-machine relationship because self-confidence is equally vital when it comes to operating machines.

Self-confidence could be instilled by training but the real test of self-confidence occurs when one confronts or operates a particular machine. Familiarity and exposure enhances self-confidence. In interacting with a machine, self-confidence may exist to varying degrees depending on familiarity, exposure, training, skill, knowledge, etc.

A micro-analysis of self-efficacy (self-confidence) and behavioural change revealed that self-efficacy gave an accurate predictor of performance on tasks varying in difficulty (Bandura, 1977).

"The operative process involved in the relationship between efficacy expectations and actions needs further investigation" (Bandura, 1977). Thus, the study of mismatches and self-confidence in this thesis is expected to highlight and increase our understanding of the relationship between these two variables.

Together with preferences, trust and self-confidence form another dimension in human-machine relationships. These are important concepts in manufacturing and production.

2.4.4.4. Conclusion

Two main categories of systems, namely manual and automated systems are frequently chosen as the subjects for investigation and research. This is particularly true but previous work is severely lacking from human perspectives especially in the area where interaction between human operators and systems occur. Designs of automated systems should evolve from the skills and tasks of manual systems giving serious consideration to human attributes. Technological achievement should not be the sole basis of design, but rather, acceptance by human operators should also be considered. Therefore, the ultimate objective of this research is to establish the preferred level of automation in line with the highlighted issues.

2.5. Initiatives in Manufacturing

2.5.1. Current Status

The term mismatches has not specifically addressed issues in manufacturing studies but rather references have been made to production disturbances and unscheduled manual interventions. In field studies of production disturbances in flexible manufacturing systems (FMS) a rate of 12% was recorded in the USA compared to 35% in Finland (Jarvinen et al, 1996). These figures were rather alarming to manufacturers because disturbances might affect high utilisation of manufacturing capacity.

Similarly, in a study of automated systems by Hockey and Maule (1995), it was observed that unscheduled manual interventions have occurred more frequently than previously claimed. These imposed a heavy workload on operators.

Both the above studies investigated problems in automated systems. No reference was made to manually-operated systems although it is anticipated that similar problems could have been diagnosed in such systems where problems could have been identified and be remedied in the design and installation of automated systems.

In another study on machining, operators' requirements were investigated related to the occurrence of unexpected events and operators' psychological requirements (Martensson, 1996). According to an attitude survey in Swedish industry (Martensson, 1995), "the operator's natural requirements for work are versatile job content, responsibility and participation, information processing, influence on the physical work performance, contact and co-operation, and competence development".

The above investigations have revealed critical issues concerning psychological responses on the part of the operators but provide hardly any clear understanding about the relationships between human incompatibility (mistakes or mismatches) and machining tasks.

2.5.2. Technological innovations

An algorithm to obtain optimal solutions to machining economics-operations sequencing problems was developed in a study by Koulamas, (1993). The determination of the sequences and the cutting speeds for a number of operations performed using the same tool were examined where optimal cutting speeds differ between operations. The study highlighted one (technical) aspect of manual machining problems but did not consider machining performance by the human operator with respect to selection, setting-up and inspection tasks as intended in this research.

There was an absence of the human component in a study to assess Total Machining Performance (TMP) by Fang and Jawahir (1994). Fuzzy-set theory was used to assess the physical aspects of machining attributes such as surface finish, tool-wear rate, dimensional accuracy, cutting power and chip breakability. Efforts are needed to develop and expand effective knowledge acquisition through the integration of the expert's experience, experimental results, empirical rules, machining theories and data from existing machining data handbook etc. The study was intended to optimise machining performance but there was a flaw in its claim of totality due to lack of consideration of human characteristics.

With Computer-Numerical Controlled (CNC) machine tools, it has been reported that there is a tendency for increased failure probability. The problem of reliability becomes more and more important. Reasons and rules of failures have not been fully investigated which results in inefficient running order of automated equipment (Yazhou et al, 1995). Understanding mismatches in machining operations, investigated in this research, should provide the basis to improve the reliability of such machine tools.

2.5.3. Conclusion

Efforts and achievements are the impetus to manufacturing developments. Review of the literature reveals that there are gaps in manufacturing research that could possibly be enhanced. Endeavours have been extensive but found greater emphasis on hardware and software that far outweigh the "humanware". It is the intention of this research to establish the relationships between variables of human characteristics to psychophysical (mismatches) and psychological (trust, self-confidence and preference) outputs of human performance. Findings are expected to clarify related issues and the results of other impending developments.

2.6. Conclusion

This chapter has presented insights into human performance in machining in relation to various aspects which include psychological theory, task performance and machining operations. In addition, this chapter has discussed the differences between manual and automated systems from the perspectives of occupational safety, machining skills and the effects of robotization on operators' work. The final part of this chapter described some initiatives in manufacturing.

While research exists on the ergonomics aspects of manufacturing, human errors, automation, trust and self-efficacy, none exists which investigates the influence of basic human characteristics (age, skill and work experience) on physical outcomes (mismatches) of activities (turning operations). Thus, the need to investigate issues in an effort to establish relationships between particular variables.

By and large, studies on human performance in manufacturing are not plentiful when compared to technological studies. Numerous attempts were made on various selected aspects aimed at improving human performance and the efficiency of machining operations in manufacturing. Relationships between machining tasks and errors were not well covered in the literature because quantification was mainly obtained by simulations and models. Studies with validation based on both laboratory experiments and field studies are unavailable.

CHAPTER 3

RESEARCH HYPOTHESES

3.1. Introduction

"People, particularly those used to operating machines, grow to expect certain things to happen. Contravention of any stereotypes by design is in fact building in an increased likelihood of mistakes" (Singleton, 1976). Expectations for events with mistake or non-mistake consequences are second nature in the working environment. A formal understanding of these expectations is unlikely to come solely from objective analysis and hence relevant subjective factors need to be considered in a complementary way. Similar understanding applies to the occurrence of mismatches in typical machining operations. There is a likelihood of mismatches occurring between expected tasks and the actions performed by machine operators. Since mismatches, like errors, involve human behaviour, the primary sources include slow or over-fast reactions, trust, self-confidence, attention, memory and misapplications.

In this research, hypotheses have been developed using the extensive literature review as the primary source plus secondary sources such as personal experience and knowledge.

3.2. Mismatches

Rasmussen (1980) considers an event to be a human error if it occurs in the early stages of training, but that it cannot properly be considered as such if it happens after skilled routines have been developed. Instead, faults and errors may be defined basically as causes of unfulfilled purposes. Anticipation of events is a pre-requisite in fulfillment of tasks, and thus the development of anticipation is clearly very important for highly skilled performance. This is because predicting task cues helps to offset the delay of responses and thus assists in achieving proficiency or skill (Holding, 1981). The ability to trade-off speed and accuracy has been shown to improve the skill of operators (Siddal et al, 1957).

With reference to manual turning operations, work routines usually involve machine setting tasks, inspection tasks, detection of faults, correcting actions and location of fault sources. Setting tasks involve setting the main controls, the workpiece, tools, speeds and feeds. Inspection tasks could for example involve visual checks on the condition of the workpiece, faults being identified by the detection of surface flaws. Correcting action proceeds by adjustment of the machine controls or tools. In some cases the fault sources can be located. When the operator undertakes a search for error causes or visual evidence of errors, anticipation of faults is necessary so as to take action to prevent the occurrence of faults and damage to the workpiece. Effective job performance is related to avoidance or reduction of down time on the production line through these fault-correcting actions (Chadwick-Jones, 1969).

Mismatches have been considered as one of the less well-recognised effects in man-machine interaction (Corlett,1980) and, therefore their relationships with other human characteristics have not been fully established.

In the current study, mismatches are defined as follows:

> *Actions which are inconsistent, incompatible, inappropriate and unsuitable to what is expected and is required. If these mismatches remain uncorrected they become errors.*

In relation to mismatches, human operators have some particular characteristics that need close analysis. The nature and frequency of occurrence of the mismatches are considered important in understanding the phenomenon. Thus, it is essential for studies to determine the nature of the mismatches by establishing how they relate to other variables like skill, working experience, age, self-confidence and level of trust.

3.2.1. Hypotheses 1,2,3,4 and 5.

Taken together, the following hypotheses predict that skilled operators experience a low rate of mismatches in turning operations, and that conversely, lowly skilled operators experience a high rate of mismatches.

Hypothesis 1 :

The higher the skill level of operators, the fewer mismatches are committed.

Logically, the probability of successful performance should relate to low rates of mismatches. Likewise, it was shown by Bandura (1977) that the probability of successful performance for any given task is a function of the strength of efficacy expectations is as plotted in Figure 3.1. i.e. high self-confidence leads to a high probability of successful performance.

The arguments above allowed the formulation of the following hypothesis.

Hypothesis 2 :

Operators having high self-confidence commit less mismatches.

When operators mistrust automation they may use it inappropriately (Muir, 1988). Technological sophistication and complexity of systems give rise to operational changes in machining. Trust of technology, and hence systems, is the pre-requisite for compatible relationships between operators and machines. Muir (1988) suggested that inappropriate use of automation resulted from mistrust by operators. Similarly, in manual systems, operators' trust should influence their reliance on particular systems where any mistrust might lead to an inappropriate task allocation strategy (Lee and Moray, 1994). These arguments suggest that mistrust could lead to mismatches and a high level of trust should allow a low occurrence of mismatches. Thus, the following hypothesis was developed :

Hypothesis 3 :

Operators having a high level of trust commit less mismatches.

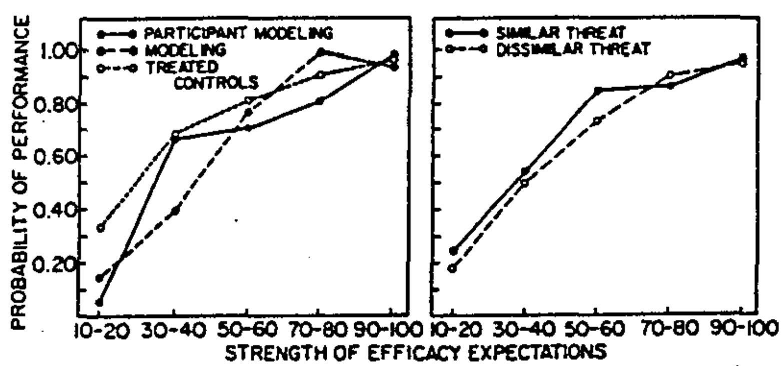


Figure 3.1. The Probability of successful performance as a function of the strength of efficacy expectations (Source : Bandura (1977))

Older operators might be expected to have more experience both through training and practical working experience. This experience collectively appears to benefit the quality of older workers where their steadiness and ability to work have been rated better than that of younger workers (Davies and Sparrow, 1985). In computer work, experience was a significant predictor of performance where people with more experience performed better in terms of both speed and accuracy (Czaja and Sharit, 1993a, b), Sharit and Czaja (1994). A similar opinion was also expressed by Avoleo et al, (1990) who showed that experience is an important indicator of work performance. Thus, hypothesis 4 was developed to establish the relationship between working experience and the occurrence of mismatches.

Hypothesis 4 :

The longer the working experience the fewer mismatches committed.

Aging is a phenomenon related to changes in physical maturity of organisms in the body and these changes are believed by some to be essentially due to environmental factors (Welford, 1958). Therefore, age has been the focus of research for a considerable period of time. Age has been taken as an independent variable against which to compare changes in human characteristics or capacities.

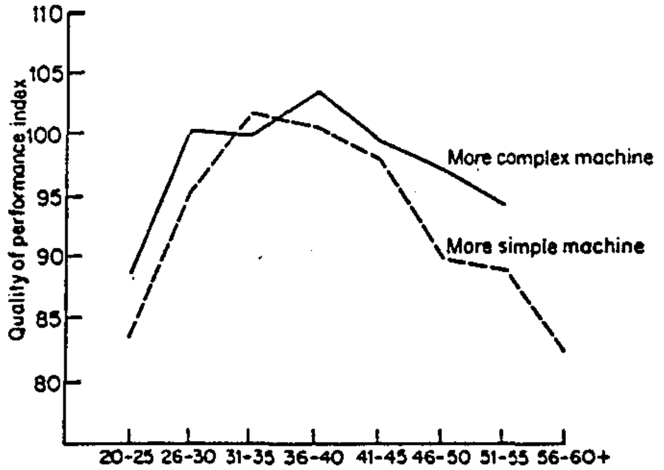


Figure 3.2. The relation between age and quality of performance index
(Source : Davies and Sparrow, 1985)

It has been found that errors increase with age and the difficulty of tasks (Kay, 1954). Research has also shown that the level of performance in terms of speed, accuracy or probability of adequate performance deteriorates with age. It is also clear that older people are at a disadvantage because they tend to make errors in task performance (Welford, 1958). Figure 3.2 illustrates this relationship and the broadly similar conclusions reached by Davies and Sparrow (1985).

Logically, this is readily acceptable because aged operators tend to be more forgetful compared to younger operators. However, mismatches are mostly related to reasoning and judgement in specific tasks that normally come with working experience and length of exposure. This is inherent in older workers and thus less mismatches are expected of them. However, Rhodes (1983) was of the opinion that job performance did not decline with age.

In another study among coalminers, Whitfield (1954) pointed out that younger accident-prone subjects failed to appreciate the demands of situations while older accident-prone subjects failed to produce appropriate responses to situations that result in accidents. Older workers recorded lower accident rates than younger workers but there were important differences in the causes of accidents for the two groups of workers (Doering et al, 1983). Accidents, human errors and mismatches are closely related, allowing the formulation of the following hypothesis.

Hypothesis 5 :

The higher the age of operators, the fewer mismatches committed.

3.2.2. Summary.

Work involving multi-facetted tasks are problematic and require skill for their successfully execution. Self-confidence, trust, work experience and age each contribute to an operator's performance at work.

3.3. Self-confidence

Bandura (1982) stated that "self-percepts of efficacy influence actions and showed by causal tests that the higher the level of induced self-efficacy, the higher the performance accomplishments". The expectation is that high performance would normally be accomplished by skilled operators rather than low or unskilled operators. Thus, higher self-confidence is usually associated with higher skill levels of operators.

3.3.1. Hypotheses 6,7,8, and 9

The following hypotheses are developed :

Hypothesis 6 :

The higher the skill level of operators, the higher their self-confidence.

In the psychological literature, one definition of trust in another person is "the degree of confidence you feel when you think about a relationship" (Rempel and Holmes, 1986). When an operator performs machining work on a machine, a unilateral relationship is established. This relationship is enhanced if the operator's trust of the machine grows. This trust should reciprocate back to the operator instilling self-confidence. Therefore, a higher level of trust should correspond to high self-confidence. Hence, the development of hypothesis 7.

Hypothesis 7 :

The higher the self-confidence, the higher the level of trust.

It has been shown that "self-efficacy both caused and was caused by performance experiences. Efficacy was significantly related to performance, and performance was related to post-task self-efficacy" (Silver et al, 1995). Similarly Feltz (1982) showed that experience improved performance, and subsequently self-efficacy. These findings led to the formulation of hypothesis 8.

Hypothesis 8 :

The longer the working experience, the higher the self-confidence.

Although human organisms suffer impairment from the age of the late 20's onwards, the effects are substantially offset by learning and experience (Welford, 1958). As learning and experience increase, so does the level of trust and self-confidence. Hypothesis 9 was developed to investigate this effect.

Hypothesis 9 :

The higher the age of operators, the higher their self-confidence.

3.3.2. Summary

Efficacy influences actions that improve performance accomplishment. Trust, work experience and age are basic human characteristics inherent to human operators.

3.4. Trust

Errors due to mistrust and choosing inappropriate actions are biases that must be overcome. Recalibration of trust should follow which should correspond more closely with objective measures of systems' or machines' trustworthiness.

3.4.1. Hypotheses 10,11 and 12

Suggestions to improve calibration of trust (Muir, 1994) indicate that skill is particularly essential in overcoming mistrust and the inappropriate allocation of choices. This relationship between skill and trust was investigated with hypothesis 10.

Hypothesis 10.

The higher the skill level of operators, the higher the level of trust.

"One of the functions of trust is the reduction of complexity and uncertainty" (Luhman,1980). Experience helps in building up expectations of other people's competence and responsibility, and an expectation of persistence of expertise. Experience undoubtedly helps operators in calibrating their trust of machines whereby trust is adjusted to correspond to an objective measure of trustworthiness (Muir, 1994). Thus, hypothesis 11 was developed relating trust and experience.

Hypothesis 11.

Operators having longer working experience show higher levels of trust.

Enhancement of predictability, dependability and faith are the keys to the growth of trust in the relationships between humans (Rempel et al, 1985). Similar factors should prevail in human-machine relationships depending on human maturity, receptiveness and length of exposure. Under normal circumstances, older people show higher maturity, and a higher level of trust in machining. These arguments establish hypothesis 12.

Hypothesis 12.

The higher the age of operators, the higher the level of trust.

3.4.2. Summary

Mistrust cause uncertainties and reduces performance. Work experience and age could affect the level of mistrust in human operators, and hence work performance.

3.5. Preferred Levels of Automation

Machine operators should no longer be treated as trainable users whereby training is given to improve shortcomings. Instead, machine operators need to be treated as humans and thus a complete understanding of human physical and mental capabilities is essential. Humans can be trained, are capable of reasoning, make choices, have preferences and reject faults. Thus, machine operators show the characteristics of consumers and need to be treated as such.

Machines need to be treated as consumer products whereby an optimal level is required to maximise consumer preferences (Feldman, 1971). This is particularly essential to designers and manufacturers of particular machines who might wish to optimise operator-machine relationships.

There have been radical changes in human task requirements due to rapid technological development over the past 30 to 40 years. Increased automation of systems has made operators increasingly remote from machines and processes and this generally permits only a very prescribed degree of interaction between them (Reason, 1990). It has also been stressed that effective vigilance is not normally sustainable even by highly motivated operators and that special aids are required. De-skilling of operators has become a normal consequence of automation (Smith and Small, 1984), (Reason, 1990).

As for manual controls and activities, skilled practices should be continuous in order to maintain them. Training and proceduralisation of operators' actions are then useful in overcoming foreseeable faults (Reason, 1990). It is not particularly uncommon to observe mismatches committed by operators when manual tasks are being performed on any particular system or machine.

The discussion above has elaborated on the shortcomings of human intervention in system operation. Faults in operators' actions should be studied and need to be matched up with compatible levels of automation of machines or processes. This in turn would reduce the chances of unpreparedness, forgetfulness, de-skilling and other negative responses prevalent among operators of automated systems.

Mismatches occur in manual operations because there are many task elements that need to be performed by operators. Operators who realise their shortcomings (mismatches) could possibly indicate their preferred level of automation so that compatible design of systems could be achieved. This is in line with the user-centred concept commonly understood in human factors engineering.

3.5.1. Hypotheses 13, 14, 15, 16, 17 and 18.

The following hypotheses are established :

Hypothesis 13.

Operators who prefer higher levels of automation, commit less mismatches.

Goldstein (1971) pointed out that performance under preferred conditions would show two characteristics :

a) The most exact execution of the required task under the circumstances given.

b) Tasks are executed with a feeling of comfort and ease, of fitness and adequacy. Natural performances under not-preferred conditions are experienced as disagreeable, unsatisfactory and unnatural.

Hence, hypothesis 14 is established :

Hypothesis 14.

Skilled operators prefer lower levels of automation.

It was established by Lee and Moray (1994) that trust and self-confidence were two factors that could guide operators' interactions with automation. Generally, when trust exceeds self-confidence, automation is used and when self-confidence exceeds trust, manual control is used. It was also suggested that the capabilities of automation were reflected by trust, and the ability to control systems manually was reflected by self-confidence. Hence, both the relationships between level of automation and self-confidence above and between level of automation and level of trust could be used to determine the preferred level of automation for operators of manually-operated centre lathes. These arguments provide the basis for hypothesis 15.

Hypothesis 15.

Operators having high self-confidence prefer lower levels of automation.

The level of human involvement that optimizes system performance is influenced by the trust that the operator has in the machining system. Trust and the consequent choice of automatic or manual control interacts with the quality of the automation to affect system performance. It has been suggested (Table 3.1) that trust corresponds to poor quality of automation (Muir, 1994). In this research, the intention was to establish the relationship between trust and preferred levels of automation. This results the formulation of the following hypothesis :

Hypothesis 16.

Operators having a higher level of trust prefer a lower level of automation.

Operator's trust and allocation of function	Quality of the Automation 'Good'	 'Poor'
Trusts and uses the automation	Appropriate trust, optimize system performance	False trust, risk automated disaster
Distrusts and rejects the automation	False distrust, lose benefits of automation, increase operator's workload, risk human error	Appropriate distrust, optimize system performance

Table 3.1. System performance influenced by operator's trust in and use of automation.
(Source : Muir, 1994)

"Experience is a positive attribute of age" (Nadler, 1981). A wide range of skills, knowledge, ability and willingness for responsibilities and to act independently are the result of experience and age (Robinson et al, 1984). Experience can be synonymous with age and thus both factors have influence in evaluating and achieving compatible system design.

Working experience on a system provides the scope to make choices particularly on the preferred level of automation. This is important considering the fact that operators' experiences are more varied in nature while there is little variation in machine design. Machines need to comply to specific design requirements so that designers' errors make significant contributions to accidents and events (Reason, 1990).

Thus, it is important that an ideal design of an automated machine should cater for a broad range of operators from various levels of working experience. Such an ideal machine should lead to a reduction in the problems faced by operators in comparison to conventional machines.

Hence, a relationship between preferred levels of automation and working experience is needed to establish a better understanding of machine-operator compatibility.

Hypothesis 17.

Operators having longer working experience, prefer lower levels of automation.

"Age as a design variable has potentially important implications for the composition and function of any system" (Robinson et al, 1984). It is essential that operator-machine compatibility is achieved by considering the disadvantages of age (reduced sensory abilities, physical strength, etc.). "Human factors routinely views task performance as being a function of the congruence between operator capabilities and environmental demands relative to the task to be performed" (Faletti and Clark, 1984).

In the field of advanced manufacturing, automation might be considered as a major technological change particularly to aged workers who might have difficulty with its acceptance (Coberly and Morrison, 1984). It was the opinion of Smith and Small (1984) that new technology resulted in the lowering of skill requirements, simplification and routinisation of tasks, reduction in individual judgement and a loss of social contacts that could be appealing to older workers. In fact, technological change (or automation) has been linked with the state of health and stress experienced particularly by older workers (Crimmins, 1984).

These considerations lead to hypothesis 18.

Hypothesis 18.

Older operators prefer lower levels of automation.

3.5.2. Summary.

Levels of automation provide choices for human operators. Variable human characteristics might influence the variations of the levels to achieve compatibility between human operators and automation.

3.6. Conclusion

Mismatches may be considered as a set of foreseeable, yet unavoidable faults that may haunt operators. It is in the interest of machine design, job design and the psychological aspects of human performance that a study should highlight the problems. Since mismatches are human events, there is a clear need to establish relationships between mismatches and basic human characteristics.

Even though automation is widely accepted, the acceptability to operators (users) should not assume a blanket approval. A study is thus necessary to identify any misappropriateness and shortcomings between automation and operators.

The methods used in investigating the hypothesis formulated in this chapter are described in the following two chapters.

CHAPTER 4

OVERVIEW OF PROCEDURES

4.1. Introduction

Consequent to the background study, literature reviews and research hypotheses, an overview of procedures that have been used by other researchers is provided in this chapter. These are essential in providing justification for the establishment of the methods specific to the current study. Outlines of the methods used are given briefly and compared to previous methods. Issues are highlighted that provide reasons for selecting the particular method in the study.

The review of the literature showed that a limited number of techniques have been used in similar research disciplines. The limited variety is due to the nature of the research problem which requires a reliable method based mostly on subjective measurements. Objective methods are not frequently encountered due to the subjective nature of humans and their responses. The evaluation of man-machine systems should ideally include both objective performance data and subjective participant data to present a thorough picture of system performance (Scallen et al, 1995). Subjective data such as the operator's perception of their work performance might be of high importance (Lomow, 1979). Nevertheless, subjective methods should not be considered as non-scientific because mathematical methods can be used in the analysis (de Vaus, 1995).

4.2. An Overview of Literature on Procedure

In a manufacturing environment, human or workers' performance cannot be measured and accounted for as easily as in a non-manufacturing environment where simulated studies can be used. Difficulties arise from the complexity of the factors involved. "Workers' skills, creativity, and innovation become the valuable attributes where quality of work is more important than quantity" (Beeby and Collier 1986). Tests for performance may be designed to meet specific objectives but the criteria used must conform to realistic situations so as to obtain meaningful results.

Performance rating is a useful measure which provides subjective impressions while objective measures might be normally preferred. Objective performance measures pose difficulties and invariably suffer contamination from bias and noise (Hedge et al, 1994). Hence, both subjective and objective performance measures should be employed so that the results might complement each other.

Work on human error has attracted many researchers, and has led in various directions which include determining why human errors occur, devising means for dealing with them, determination of error rates and error probabilities and probabilistic risk analysis (Rouse, 1988). As an example, "in advanced manufacturing systems (AMS), accidents may be considered rare occurrences or infrequent events so that different measures of the risk or safety of a system (such as error rates or unplanned events) need to be used" (Zimolong and Trimpop, 1994). Similarly in manual turning operations, causes of mismatches between tasks and actions performed by operators are measurable and quantifiable in determining operator's performance.

Attempts to estimate human errors and their effects on man-machine effectiveness have faced several obstacles in quantification work (Swain, 1964). In structural design work, a Human Reliability Model (HRA) was developed to simulate the effect of human error, particularly multiple errors, on design computations for reinforced concrete beams (Stewart, 1992). However, in this study, human reliability (HR) was not an issue because it was merely an activity of analysing, predicting and evaluating work-oriented human performance in qualitative terms using such indices as error likelihood, probability of task accomplishment and response time.

There is no best way to measure job performance. Appropriate performance measures need to be derived from the task context, and not merely identified. The determination of appropriate job performance criteria is thus situation-dependent. Measures which are constantly valid, reliable, relevant, discriminating and free from bias in all situations where performance information is required, is an unrealistic aim which denies the complexity of the performance measurement phenomenon and sacrifices conceptual soundness for methodological purity or vice-versa. Behavioural scaling methods have thus been recommended by Bailey (1983).

Therefore, human error data are needed to determine human performance in manual machining. However, "human errors are not events for which objective data can be collected, instead they should be considered occurrences of man-task mismatches which can only be characterised by a multi-faceted description" (Rasmussen, 1987). Using a technique called Technique for Human Error Prediction (THERP), Pines and Goldberg, (1992) deduced that machine tool operators have a failure reliability of 6.90 based on manual lathe operation tasks.

Data could be collected from individuals using semi-structured interviews, document studies and participant observation or from group studies as shown in a study on the introduction and operation of FMS in a number of British, Belgian and Dutch companies (Boer, Hill and Krabbendam, 1988). Qualitative techniques were employed in establishing conclusive evidence related to the research objectives.

In another study, evaluation of the relationships between ergonomic conditions and product quality in car assembly was carried out by means of interviews with experienced assembly workers while quality deficiencies were obtained from internal quality statistics of the company and interviews with quality control personnel (Eklund, 1995). Subjective methods are unavoidable in this kind of study.

There are limitations involved in human performance studies. Limitations are mainly in measurement and precision control. In human performance studies, humans are used as subjects but they are not samples of materials from which data can be drawn to researchers' whims and fancy. Two main common measures of performance are speed and errors, but here there could be a lack of precision of control and an absence of consideration of statistical significance (Singleton, 1978).

Any analysis of human performance (Boff and Lincoln, 1988) requires supporting data in quantitative form. Objective human performance data takes the form of time, error, frequency, and logistic measures. Errors include those of :

i) omission (failure to perform or complete required activities, failure to perform a required activity as expeditiously as possible or failure to satisfy a required criterion fully),
ii) commission (performance of non-required activities), and,
iii) sequencing (performance of required activities out of sequence).

Error data are produced by matching actual performance against an explicit or implicit set of requirements. Frequency data are produced by counting numbers of operator responses, errors, outputs, and events.

There are problems in offering a precise definition of errors because of the use of variable terminology which, in addition to errors, includes mishaps, faults, mismatches, etc. According to Rasmussen (1986), human error is one instance of human-machine or human-task mismatch, the effects of which are not immediately observable and are irreversible. Human errors, considered as unsuccesful acts and consequences, are mismatches but not all mismatches are human errors because the latter shows mere incompatibility, deviations from the norm and the loss of time. Thus mismatches can possibly be overcome resulting in eventual completion or execution of tasks.

Mismatches between humans and systems have evolved through characterisation and classification of human errors. Thus their nature or dimensions is more important than their causes (Rasmussen, 1986). In this research, the types of mismatches and the reasons for their occurence were the primary targets. Subsequently, relationships between mismatches and basic human characteristics would provide reasons and enlightenment for such occurrences.

In this investigation, mismatches is a broad term used to identify the occurrence of some incompatibility i.e.a non-matching situation. These are quantified in terms of occurrence and causes as this is essential for the micro analysis of human-task relationships.

Mismatches (Rasmussen, 1987) may be expressed in terms of the commission of :

i) acts outside a procedural sequence

ii) acts on wrong components

iii) reversal of a sequence

iv) wrong timing

The mechanisms behind human-machine mismatches (Rasmussen, 1986) suggest that subjective as well as objective methods are needed for such investigations. This is because intrinsic human variability leading to mismatches during normal work situations have effects upon skill and rule-based behaviour.

Variables involving basic human characteristics, i.e. level of trust, self-confidence and preference for levels of automation inherent to this study could only be measured subjectively. Measures of self-confidence could only be obtained from the subjects involved in the study (Jones,1995) because quantitative measurements were not available. On the same basis, trust and preference, were obtainable by directly asking participating subjects.

Studies of unscheduled manual interventions (UMIs) in automated process control have been carried out based on a range of field methods such as questionnaires, interviews and analysis of process production records (Hockey and Maule, 1995). The questionnaire studies revealed that UMIs occurred much more frequently than interviews with senior managers suggested. A formal analysis of the process records for a full week's production confirmed the above observations. It was clear that multi-methods were suitable for research of this kind where the data were supportive and confirming.

Adler (1991) used comparative studies of two installations enabling primary data to be collected using responses to questionnaire surveys designed to determine workers' assessments of flexible manufacturing systems. In a study of performance effects of technological development and of human resource management development, data were gathered through analysis of annual reports and case and project descriptions provided by companies, complemented by telephone interviews using a structured interview technique (Horte and Lindberg, 1994).

Questionnaire analysis has also been used in the study of attitudes of workers faced with new computerised technologies (Marquie et al 1994).

4.3. Methods Used by Other Researchers

Williams (1988) introduced a practical methodology to allocate automatic and manual functions at the design stage. The method attempted to identify tasks that required automation, and facilitated the striking of an appropriate balance between operator action and automated operations.The methods employed were the Functions Analysis System Technique (FAST), Time-Line Analysis, aggregate Task Difficulty and Criticallity Rating (aggregate TDCR) and the Examination of the Source of Task Loading (ESTL). FAST permits the generation of a hierarchical form of task analysis, Time-line Analysis depicts the sequencing and duration of each operator task, aggregate TDCR permits the assessment of potential workload and refers to a known task while ESTL examines sources of task loading.

Search strategy score (Landerweerd, 1979) has been employed whereby a scoring procedure was based on a comparison of the strategies used by the subjects with the "nearest" correct strategy, and the number of errors counted for error categories which included :

i) errors of omission (the subjects' failure to ask for one or more relevant instruments),
ii) errors of redundancy (one or more irrelevant instruments were nevertheless asked for),
iii) errors of confusion (erroneous order of instruments to be inspected)

The Human Error Identification (HEI) technique has been applied to public technology (for example a drink vending machine) to compare between predicted and observed use (Baber and Stanton, 1996). HEI was used to define points in the interaction between humans and artifacts, or systems which are likely to give rise to errors. Typically, this was achieved through four related practices :

i) representing the full range of operations that people can perform using the artifact or system;

ii) determining the types of errors that are likely to occur;
iii) assessing the consequence of errors for system performance;
iv) generating strategies to prevent, or reduce the impact of errors.

There is some similarity in terms of the techniques used in the study above to that used in this particular research, but Baber and Stanton's study stopped short of establishing psychological connections between variables of human characteristics and did not provide quantitative information.

Many other forms of task analysis have been used, such as Hierarchical Task Analysis (HTA) (Stammers and Shepherd, 1995), Goal-Operator-Method-Selections (GOMS) (Card and Moran, 1980), Computer-aided function allocation Evaluation System (CAFES) (Sanders and McCormick, 1993) and Sequence Task Allocation (STA) (Drury, 1983).

HTA is carried out by breaking down a task into a number of task components at various levels of description while GOMS provides a structured language to analyse tasks. CAFES is a computerised design aid that allows designers to assess potential problems and STA provides a rigid pattern for a sequence of tasks. The method used in this research has similarities with Sequential Task Analysis (STA), (Drury, 1983; Kirwan and Ainsworth, 1992) which looked at operators' actions as they occurred in chronological order.

It has been pointed out (Baber and Stanton, 1996) that relying on user opinion is problematic for three main reasons :

i) it assumes that the user is a good judge of what makes an effective technique, rather than simply being able to say whether that technique has " worked " for that user;
ii) user opinion is based on previous experience, and unless there is a high degree of homogeneity of experience, opinions will vary widely;
iii) judgements may be obtained from an unrepresentative; i.e. biased, sample.

Field difficulties were encountered in quantifying the causes of mismatches for typical tasks or machining operations for which a subjective method (questionnaire survey) was employed in this study. The questionnaire allowed subjects to give appropriate causes for mismatches from a group of identied causes for a particular machining operation. It was expected and presumed that the causes given would cover a broad range of tasks for which it was not feasible to use quantitative methods.

Questionnaires and experimental methods were used on the same group of subjects to test the hypotheses by subjective and objective means respectively. Similiar objective and subjective methods have been used in previous studies (Lavender and Marras (1990), Evans (1990) but the simultaneous use of both methods is rarely found.

Therefore, the relationships between relevant variables were established using two different techniques i.e. quantitative and subjective methods, that was considered unique in this study.

4.4. Variables in the Hypotheses

The discussion above highlights methods that others have used in similar research areas. Contribution to knowledge might be sought through the experimental design of the variables (factors) identified in Chapter One and Chapter Three. Variables need to be identified and data collected for the purpose of testing the hypotheses.

4.4.1. Variables in simulated-field studies (SFS)

In simulated-field studies (SFS), the causes of mismatches between operator and machines might be obtained through observations of operators performing particular tasks. A prepared check-list is required to record the total number, types and causes of mismatches.

4.4.2. Variables in the questionnaire survey

a) Causes of mismatches

In survey work, causes of mismatches might be obtained from subjects who, from past experience, identify the causes of mismatches that might be committed in elements of machining operations. Various elements covering the overall turning operation could be posed to subjects for identification process.

b) Personal details

Information such as the age, skill and experience of operators is best obtained directly from subjects through questionaire surveys. This information forms the set of basic human characteristics essential in investigating the hypotheses.

c) Self-confidence and trust

Self-confidence and trust are both continuum characteristics where subjects might record a subjective value on some suitable scale. For objective analysis, discrete scales were used to indicate the varying levels, and were obtained through questionnaires.

d) Preferences for levels of automation

Preferences for levels of automation is a subjective measure that was captured using discrete scales obtained through questionnaire surveys.

e) Occurrence of mismatches

Consideration of the background to mismatches in turning operations places equal importance on understanding the issue and the factors related to it. The questionnaire survey was used to obtain the reasons for the occurrence, effects and suggestions for the prevention of mismatches.

4.4.3. Ergonomics considerations cause of mismatches

The possible causes of mismatches for the current study were selected based on problems typical in manual turning operations. Emphasis was placed on the human aspects of task performance and the ergonomics aspects of equipment.

In this research the occurrence of mismatches provides data that covers every type of error generated by operators. For example: Assistance is sometimes required would apply to cases when operators seek assistance when facing a difficulty that prevents the continuation of machining operations. The categorisation of mismatches typical to manual turning operations has been formalised by the author based on the unspecific and incomplete suggestions arising from the work of Rasmussen, (1977) and Reason, (1990). The author's categorisation is as shown in Table 4.1.

4.5. Research Method

In this research a method was developed to establish the relationships between human characteristics and mismatches in manual turning operations. This method resembles the TDCR method mentioned above except that it makes use of mismatches, self-confidence, trust and preferred levels of automation as the variables whereas TDCR made use of a performance factor, task difficulty and task criticality as the variables. Self-confidence and trust were investigated because both factors contribute to the requirements of automation (Lee and Moray, 1992).

Mismatches	Anticipated Considerations from Ergonomics Perspective	Typical likely occurrence
1. Intrusion	Flaws in training, low trust, low confidence, lack of information	Ask others how to proceed,in need of help
2. Omission	Flaws in training, procedural problems, sequencing, time mitigation	Particular step not not done even though machining is possible.
3. Commission	Possible absence of critical memory	Not the right way to perform a step
4. Reversal in sequence	Memory lapse, too much information	Repeat steps because a step is left out
5. Wrong request	Identification	Request for wrong items
6. Acts on wrong components	Identification	Specific items are used for wrong purpose
7. Repetition	Mechanical failures, Time mitigation	Right steps but are repeated due to mechanical problem
8. Misapplication	Training failures, lack of knowledge, and information, time mitigation	Wrong way to carry out certain method
9. Violations	Time mitigation, simplify procedures	Steps contravened normal and acceptable procedures

Table 4.1. Ergonomics considerations and likely occurrences and cause of mismatches.

The method should involve both empirical and psychological tests combined to establish relationships between psychological and physical variables. Psychological tests are used because they allow approximation by the collection of a systematic sample of behaviour, whereas the quality of the tests is largely determined by the representativeness of the sample. Three general categories of psychological tests (Murphy and Davidshofer, 1991) are :

i) Tests in which the subject performs some specific tasks.
ii) Tests that involve observations of the subject's behaviour within a particular context.
iii) Self report measures.

Systematic observations of behaviour in naturalistic situations are preferred because this technique is particularly useful in assessing attributes such as skills and the subjects' performance on their own machine.

In the method, mismatches are to be quantified based on the performance of task elements in identified machining operations, and the total mismatches are to be compared to the expected matching tasks performance inherent to ideal operators.

Machining operations can be divided into three distinct categories, namely selection, setting-up and inspection. These are decision functions found in any machining operation. Selection functions provide decisions concerning the choosing of particular items essential for successful completion of a task. Set-up functions provide decisions concerning preparation procedures carried out before actual cutting takes place. Inspection functions provide decisions concerning the acceptability of a product subsequent to machining.

In each category, particularly in manual turning operations, mismatches are prone to occur due to the weaknesses of human operators and machine design or construction. Decisions made during the selection, set-up and inspection functions should ideally be accurate, exact or relevant to each particular element of the tasks. Failure may result in time loss, re-work, scrap products and low productivity. A suggested model for the development of the Human Task Mismatch Matching (HTMM) method is as shown in Chapter One (Figure 1.4).

The HTMM method is unusual in the sense that both simulated-field study and questionnaire survey techniques are employed as a contribution to the generation of reliable and valid results.

4.5.1. An outline of the simulated-field study (SFS)

In order to define the type or causes of mismatches which could occur in the operation of manual centre-lathes, one could build and test prototype machines. However, this was considered unacceptable to the present study as it is considered important to conduct the study in normal working environments.

Laboratory data are most highly controlled, but because of this, often represent artificial situations and are difficult to apply meaningfully to real-world problems; it is difficult to generalise the results to other conditions (Boff and Lincoln, 1988). Laboratory experiments may be improvised to suit a research design that is in many cases different from that found in realistic situations. In the current study, the experimental design was established and maintained to resemble realistic situations in typical machining environments.

The sub-elements of attentional failures are considered mismatches and each is matched to each element of machining tasks. The matchings are given weightings to enable quantification in the human-task mismatch matching process. The process may be repeated for different types of machining operations both for manual and automatic workstations. This approach assumes that every task should be performed with the ultimate aim of doing it right.

The method used in the SFS is called the human task mismatch matching (HTMM) method for the simple reason that each sub-task is matched to any possible mismatches for which weightings are allocated. This method was developed to evaluate the performance of human operators in machining functions, but as is the case with any performance measure, it is suspect since subjects might be expected to enhance their normal ability and performance level by investing more in alertness and vigilance.

The method involves observation of operators performing specified tasks. An observational method was chosen as it is especially valuable in establishing any particular conditions that apply within a situation. Even though observational methods might be criticised for the potential bias of the observer, this problem could be overcome or reduced through adequate instrumentation and procedures.

In the HTMM method, observation of the mismatches performed by operators is clearly necessary as a way of coupling the data to the (field-based simulated) FBS experiment being conducted (Sinclair, 1997). An unobstructive observation technique is used where the observer remains outside the working activities of the subjects. This method was considered preferable to participative observation, where the observer becomes part of the work group. Unobstructive observation is considered to be systematic direct observation and a standardised approach to observing people performing specified tasks. Advantages inherent to visible observation include less distraction from (the observer) and the provision of more objective and precise data capture. Being in the actual situation, the observer can organise the observation to capture peak and nodal activities, and could take a global view of the situations while subjects would know all along that he is a subject.

On the other hand, visible observation could suffer from the "guinea pig" and measurement effects when a subject alters his or her behaviour or re-evaluates his or her perceptions of methods of working. However close an observation might be, non-observation could possibly occur when an observer misses important bits of behaviour or information due to the speed of events.

Human recording is a suitable means of data capture as observers are able to work in line with experiments. This could be considered the best means of capturing the unexpected events which depend on the observer's ability in assessing very complex behaviour patterns.

However, this method could suffer from a limited data capture rate due to human negligence. Observers might suffer from fatigue after long hours of observation and ablutions or nourishment might be required during the process. Beside being non-compact, obtrusive and requiring the learning of the experimental process, the data may need frequent interpretation.

Observations can be recorded through the use of a highly structured observation check-list designed to cover the tasks to manufacture a specific component sample that involves typical turning operations. The check-list relates task elements to mismatches.

On the other hand, participant observation (without an observation check-list) is a less structured type of observation thought to be unsuitable for this study. However, this technique could be applied in case studies where prolonged and uncontrolled observations are a likely method.

Several weakness to observational research include the following :

a) Actions might be restricted in not depicting the critical behaviour. Subjects should have some liberty in performing the experiment.

b) Difficulties might be encountered in one observer trying to observe too many events and record them on the observation forms.

Generally, observational research is greatly expedited by having more than one observer. Failure to use more than one observer could result in decreased efficiency and objectivity. A check list should be used to asssist and expedite observations.

c) Certain behaviour cannot be evaluated as finely as some of the items on the observation checklist dictate. The observation check-list should be designed accordingly.

d) The presence of the observer almost always affects the behaviour of the subjects. Disturbance should be reduced e.g. the observer should observe the experiment from a reasonable distance.

4.5.2. Outline of the questionnaire survey

Questionnaires can be used to test the relationships of the constructs in the model, and capture demographic information about respondents and their perceptions regarding mismatches.

Questionnaire studies can be used to evaluate, by means of subjective techniques, the performance of operators in machining tasks based on their experience, expert opinions and daily encounters at their workplace. Items on the questionnaire can be of two broad types, namely closed (subject selects a response from alternatives supplied) and open (subject provides own response).

Closed items might be used for example to gain information about the effects of mismatches on production, whereas open items could be used for recording non-specific mismatches.

4.6. Conclusion

In selecting the HTMM research method, the following issues were considered :

a) Effectiveness

The degree to which the method might accomplish its purpose. This was enhanced by the use of dual techniques (SFS and questionnaire survey) and from direct observations and operators' own responses which provided quantifiable and qualitative explanations.

b) Ease of use

The simplicity of application of the method in the laboratory or workplace as long as it involved manual centre lathes and their operators. Realistic situations should produce results representative of actual problems.

c) Cost

The minimal cost involved related to equipment, personnel, and the time needed to apply the experimental and questionnaire method. The use of sophisticated equipment such as digital video techniques would incur considerably greater costs.

d) Flexibility

The method can be used in many measurement contexts, with many types of systems and at various levels. The method is considered simple in design and easy to adapt to many situations.

e) Scope

The phenomena, behaviour, and events observable by the method could relate to a wide variety of situations and be analysed for evidence specific of those situations.

f) Validity

The extent to which the method produced data descriptive of specific behaviours or responses as they might occur in real life. In this study, several case studies could be carried out to confirm the validity of results.

g) Reliability

The extent to which repeated applications of the method to the same situation by the same experimenter produces identical data or the extent to which several experimenters who apply the same method to the same situation produces identical data. As far as reliability is concerned, using both the simulated-field study and the questionnaire survey should help to improve the reliability of results.

h) Weaknesses of the method

Both the field-based simulated experiments and the questionnaire survey are subjective in nature. Therefore a highly skilled observer familiar with machining tasks is required for data collection in order to overcome the problems normally encountered in observational research as discussed earlier (section 4.5.1).

The experimental part of the method is also a simulation of industrial situations, which although it provides manageable experimental conditions, is not completely representative of real work situations.

In summary, various methods were available for the investigation. However, it has been pointed out that "no one method satisfies all the criteria nor any of the criteria to the degree one would wish" (Meister, 1985). Indeed the method used in this study is no exception. Selection of the HTMM method was justified considering the limitations and problems that could otherwise possibly be encountered. The HTMM method was comparable to methods used by other researchers. The detailed explanation given in the next chapter provides a clearer understanding of the method used.

CHAPTER 5

THE HUMAN TASK - MISMATCH MATCHING METHOD

5.1. Introduction

Based on the review of procedures of the previous chapter, a number of possible techniques were identified. For the purpose of this research the techniques should be suitable for collecting data from human subjects and the tasks carried out (machining operations). The human task mismatch matching method aims to establish mismatches between tasks and actions by workers in manual turning operations. The method then allows relationships between mismatches and human characteristics to be determined.

This chapter constitutes a major part of the research design for the current research study. It provides systematic and detailed explanations of the methods used, the independent and non-independent variables, observational entities, development measures and data analysis techniques.

5.2. Outline of the Pilot Tests (Field-based Simulated Experiment and Questionnaire Survey).

Prior to the experiments and the questionnaire survey, a series of pilot tests for each technique were conducted to assess the proposed experimental design. This was to ensure that all possible extraneous variables, that might have adversely affected the results, were identified and removed. The performance of subjects in producing samples of components was assessed based on the mismatches committed by subjects in the FSE technique. Responses to the questionnaires were scrutinised and the questions modified for the actual survey.

The questionnaire survey was conducted in order to determine the extent of the problems in realistic field situations which involved lathe operators from a wide range of backgrounds. Preliminary to the actual survey, a pilot study was carried out to obtain responses from subjects of similar standing in order to improve the questionnaire design.

Fifteen skilled machinists participated in the pilot study of the questionnaire survey while two machinists participated in the pilot study of the field-based simulated experiment. Criticisms and comments were obtained by written comments made by the subjects and enhanced by discussion with the experimenter. This led to some amendments to the questionnaire and the experimental design that were clearly necessary. These are discussed in Sections 5.3. and 5.4.

Previous research has shown that subjects should perform experimental tasks on identical equipment throughout the experiments. This did not happen in this study. Instead, equipment at the operators' workplace was used in the experiment, and this resulted in between-subject variability in the equipment used. However, the type of machinery used was always manual centre-lathes. The reasons for this course of action were :

i) A realistic situation was maintained throughout the study. Thus the data collected relate to real working situations rather than artificial laboratory experiments.

ii) Unfamiliarity with machines would not arise. This could improve the reliability and validity of experiments by the removal of learning effects.

iii) It was more convenient if the experimenter went to the subjects rather than the subjects coming to the experimenter. This helped in reducing subjects' absenteeism from the work place, making the experimentations more acceptable to employers.

iv) Transportation costs, organisation and technical problems could be reduced;

5.3. Findings of the Pilot Tests of the Field-based Simulated Experiments.

The pilot tests established that :

a) A manual centre-lathe at the subject's own workplace should be used by each subject. The machine should preferrably be the one mostly used by the subject. The main benefit obtained was the maintainance of consistency in the type of machine used and familiarity of the machine and working environment for the subjects.

b) Drawings of the components to be produced were modified with features that required tasks ranging from simple machining to complicated tasks with several human functions which included selection, set-up and inspection functions.

c) The experimenter should ensure that instruments and tools were available within the test area. The arrangement of tools was considered trivial because the technique involved in the tests was observation of operators working at their own machine and workplace.

d) The tests should not be turned into typical laboratory experiments, but realistic conditions and situations normally found in industrial working life should be maintained.

e) Subjects should be given well-defined tasks that are common and familiar to subjects which they should try their best to perform successively. The test score was determined by the frequency of mismatches committed by subjects. The overall task (machining of a component) was identical for all subjects in the various skill categories. However, subjects were able to choose their own manufacturing sequence.

f) The experimenter should be well-versed in the actions of subjects in response to questionnaires or the tasks which make up the performance tests. The experiment should consist of machining trials to produce specified components according to typical machining operations sequence identified by the experimenter.

5.4. Findings of the Pilot Tests of the Questionnaire Survey.

a) Items in the questionnaire should cover typical and basic tasks involved in turning operations. This was to ensure that the tasks were appropriate to all operator skill levels. The primary differences between operators were the number and types of mismatches derived from the operators' machining experience.

b) The structure and format of the questionnaire required modification in terms of layout and linguistics. Simple words were used for better understanding by the operators.

c) Generally, there is a need to provide for three types of response to questions :

   i) mismatch categories (ten specific cases)
   ii) correct (one ideal case)
   iii) others (non-specific cases)

d) Responses are similar for all questions related to tasks in order to determine the number of causes of mismatches inherent to particular tasks identified. This was deliberately done to allow possible identification of causes of mismatches and the quantity committed by respondents.

e) Personal details of respondents should include working experience and skill level. All subjects were British males.

f) The questionnaire should not require a long time to fill in. Simple questions and answers were maintained throughout the questionnaire to reduce the problem of boredom on the part of respondents. The purpose was to cater for operators who were from varied and different educational backgrounds.

g) Some operators were very co-operative by taking part in the survey while there were others who did not want to admit the total number of mismatches generated by themselves simply because they were of the opinion that they had never made any mistakes in machining operations at any time in their careers. However, the number of respondents in the pilot survey were adequate to enable modifications and corrections to the questionnaires.

5.5. Experimental Design

The subjective methods contained the elements of simplicity and speed, but a quantitative method was also clearly essential to provide objective support. This quantitative method should involve laboratory work that could simulate the real work. To cover a broader range of samples, the method should be extended to a field-based simulation study and not confined to specific laboratory-based experiments.

In consideration of the subjective nature of the problem, the need for better control of the questionnaire and experiments, and in anticipation of consistent results, the experimental design should require that the same subjects be used for each pair of questionnaire survey and field-based simulated experiment.

Subjects were expected to be more serious about filling in the questionnaires in front of the experimenter and this avoided the possibility of missing data. All items in the questionnaires could be checked for missing responses and this could be rectified while the particular subject was available. The experimenter was also available to answer questions where appropriate.

5.5.1. Characteristics of the experimental design

i) Questionnaire survey

As a result of the pilot study, the scope of the research was extended to cover operator's trust, self-confidence and preferred levels of automation, and questions on these matters were added to the original questionnaire. This would give a broader context to the research particularly essential to the manufacturing discipline.

This questionnaire technique would ensure a 100% return of questionnaires but the number of respondents willing to take part might be low using this method of gathering data.

ii) Field-based simulated experiment

The field-based simulated experiment was maintained in much the same form as in the pilot studies except that more elements of machining operations were added to extend the possible tasks. Coincidently, this enhanced the sophistication of the test and increased the challenge to prospective subjects.

The new experiment would take a longer time to complete compared to the pilot study but would allow good assessment of mismatches as each subject had to perform extra elements of tasks. Both simple and difficult machining elements were added to the experiment to enhance the scope of the data collected.

5.5.2. Experimental design schedule.

The experimental design requires that the experiments be performed according to a schedule (Shepherd, 1996) involving a questionnaire survey (Q1) and a field-based simulated experiment as shown in Table 5.1.

5.5.3. Variables in the experimental design (Human-Task Mismatch Matching Method (HTMM))

Details of the variables used in the HTMM method and the measures, sources, operations and techniques relevant to each particular variable specific to the FBS experiment and questionnaire survey are shown in Figure 5.1.

Sequence	Particulars
1	Complete questionnaire Q1
2	Perform turning operations on manual lathe and produce a sample component.
3	Complete questionnaire Q1 again
4	END

Table 5.1 The schedule of the experimental design

5.6. Dependent and Independent Variables

The purpose of an experiment is to determine whether varying a parameter would cause particular outcomes. In this way, a number of plausible alternative hypotheses could be investigated thereby meeting the research objectives.

In this study, the HTMM method using both experiments and questionnaire surveys were performed using subjects who represent a number of independent variables which showed variations between subjects. It was expected that particular outcomes (dependent variables) could be obtained from the observations and questionnaire responses. The independent and dependent variables used in this study are as shown in Table 5.2.

5.7. Observational Entities

5.7.1. Field-based simulated experiment

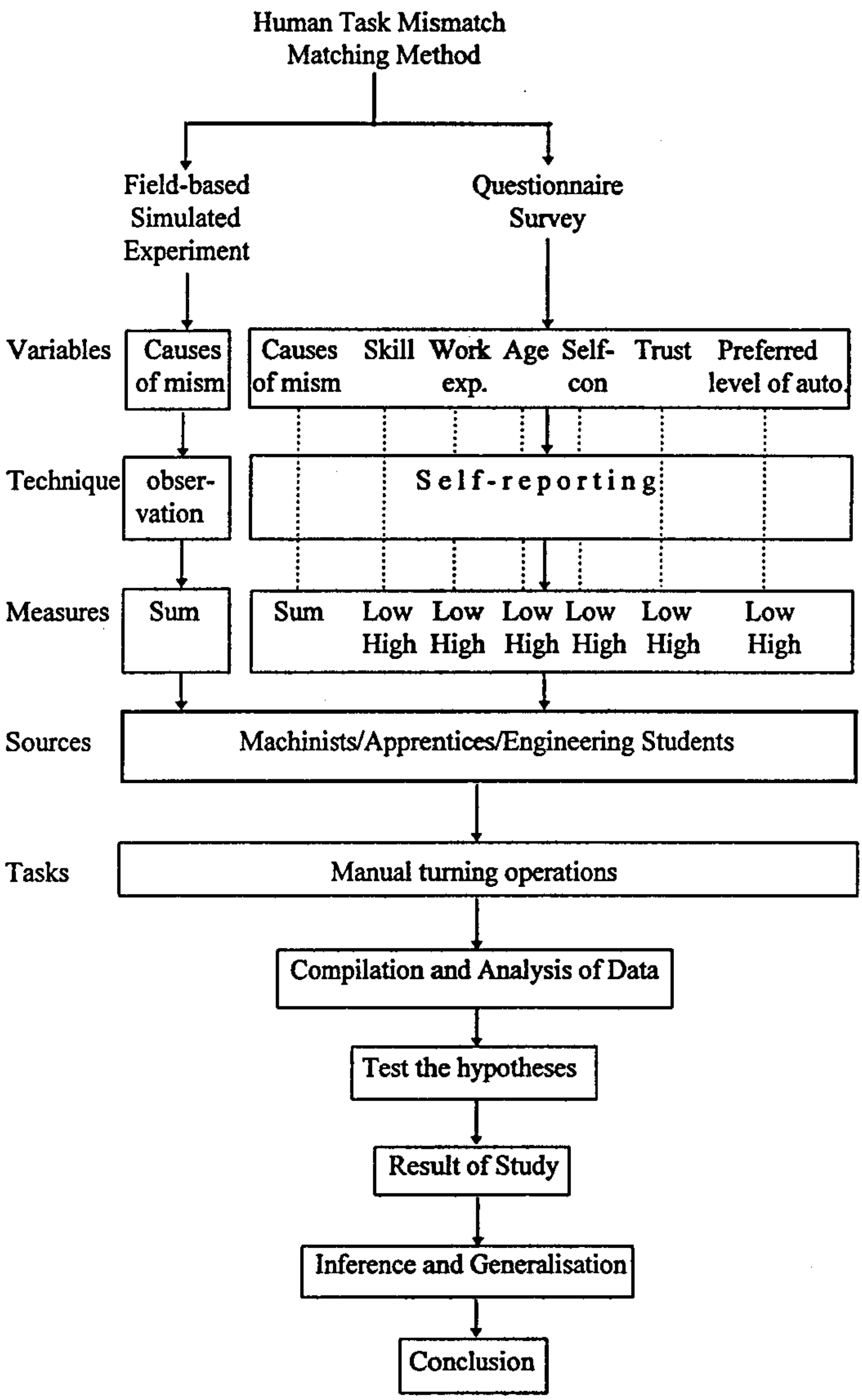


Figure 5.1. A flow chart showing the variables used in the Human Task Mismatch Matching Method

a) Task elements.

The steps of the machining sequence (elements of tasks) were identified and prepared on a record sheet as discussed in Section 5.8.4. and 5.9.3(ii). Identification of these task elements was essential for observation because these were the steps or procedures in machining to produce the specified component. In the experiment, it was necessary to choose a difficult but achievable task that was similar to a realistic demand for task performance. Theoretically, the task elements for each machining function (i.e. turning operation on a centre lathe) were similar for all subjects. However, as the subjects could choose their own working method where the sequence of task elements was not necessarily identical.

Independent Variables	Dependent Variables	Methods used to establish relationships
Skill	Mismatches	Field-based simulated expt. (observations) Questionnaire Survey (responses)
Age	Self-confidence	Questionnaire Survey (responses)
Work experience	Trust	Questionnaire Survey (responses)
Human functions on machine : Selection, Setting, Inspection	Preferred levels of automation	Questionnaire Survey (responses)

Table 5.2 The independent and dependent variables.

The task elements were grouped into three distinct categories for recording and analysis purposes, namely :

i) Selection (cognitive);

ii) Set-up (psychomotor);

iii) Inspection (perceptual-motor).

The elements were so grouped because each of them was essential in the decision-making process. In analysis each category was inter-related with the others to produce the machining operation sequence. Furthermore, the elements of the tasks were grouped to allow systematic statistical analysis of the data. The task element categories are shown in Appendix A.

b) Classes of mismatches

Mismatch categories in the study were as follows :

i)	Intrusion	:	Assistance is required before a step is executed.
ii)	Omission	:	A step in the procedure is left out.
iii)	Commission	:	A step is performed incorrectly.
iv)	Reversal in sequence	:	Due to memory failure a step or series of step are retaken. The flow of sequence is broken and steps are corrected.
v)	Wrong request	:	A mistake or error in a request for tools.
vi)	Repetition	:	Correct step but unnecessarily repeated.
vii)	Acts on a wrong	:	Wrong usage of a component or components
viii)	Misapplication	:	Wrong method is applied in executing a task.
ix)	Violations	:	The step does not comply with normal guidelines or procedures.

5.7.2. Questionnaire survey

In the questionnaire survey, the observational entities were twenty-four identified tasks comprising the three categories of task elements; selection, setting-up and inspection. The causes of mismatches (similar to that shown in 5.7.1.(b) above), self-confidence, level of trust and preferred levels of automation were also taken as the observational entities.

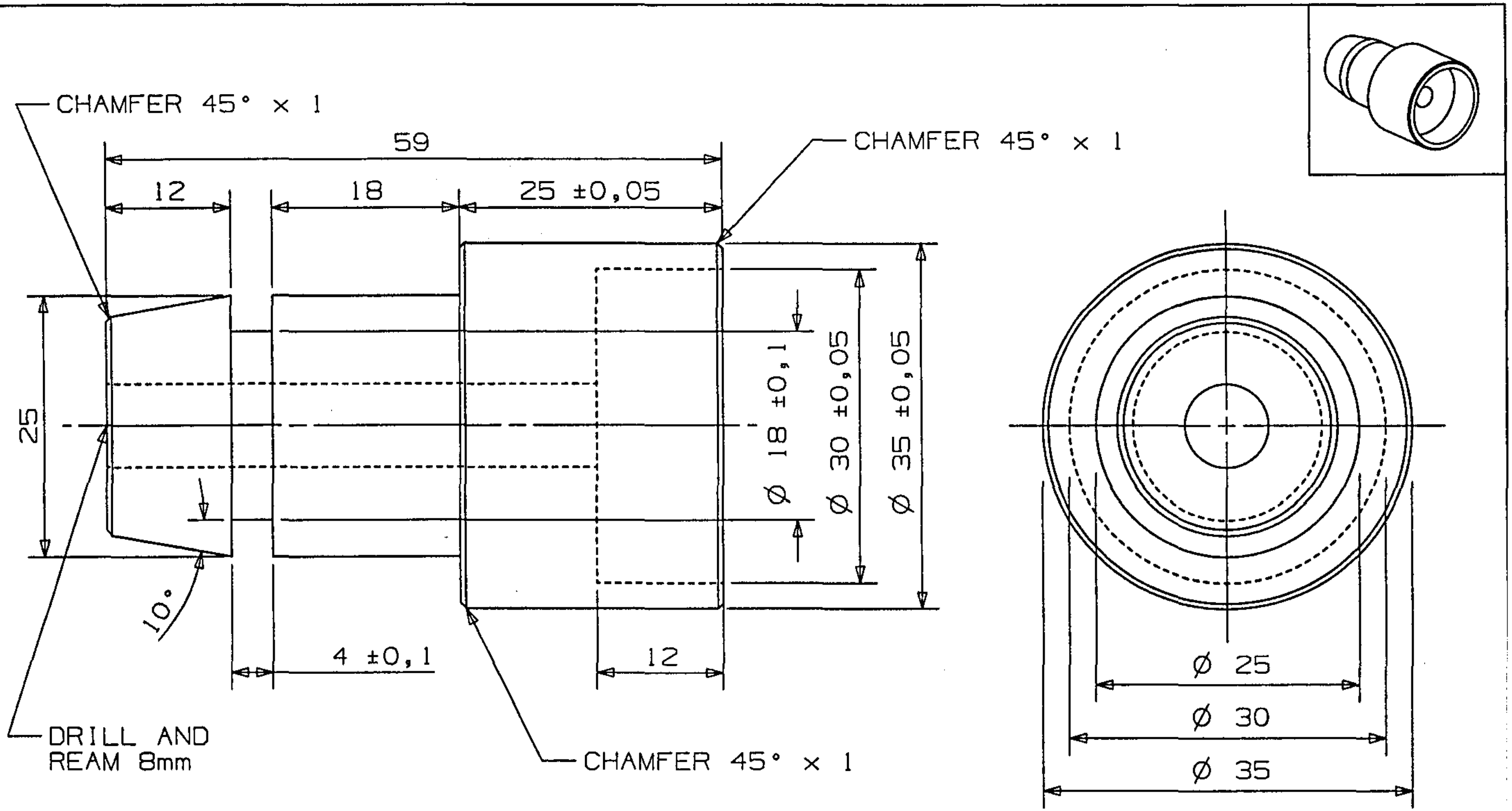
5.8. Field-based Simulated Experiments

Subjects for the experiments were selected from prospective candidates who responded to advertisements calling for subjects. Each subject was required to fill in the questionnaire before and after performing the machining experiment. A briefing about the experiment to produce the specified component (Figure 5.2.) was given to each subject by the experimenter. Special instructions were given as shown in Appendix B.

Where appropriate general aspects of the safety of the machine tool were explained to each subject by technician assistants. This was done to reduce any mishap that could possibly happen especially if machining involved operators with little experience.

Prospective candidates were categorised as either skilled or unskilled, but a prior selection condition was that subjects were British males and had some experience working on manual centre-lathes. It was observed that subjects only took ten to fifteen minutes to familiarise themselves with the machine and to understand the drawing of the component although unlimited time was allowed. Few questions were asked by the subjects because the experiment was straightforward to understand.

Permission was sought from the subjects for the experimenter to observe while subjects carried out the machining. It was explained to the subjects that the observation was solely for the purpose of student research and was not connected in any way with assesment of their normal work. Subjects were assured that their roles would contribute to research but would not be used in any way for job evaluation by management. Therefore, it was hoped that subjects would not show nervousness that might disrupt their concentration on the experiment.



LOUGHBOROUGH UNIVERSITY	THIS DRAWING CONFORMS TO BS. 308	PROJECT TITLE	DRAWN R DOYLE	TITLE Figure 5.2 A sample Component	
	TOLERANCE UNLESS OTHERWISE STATED LINEAR : 0.2 ANGULAR: 30' SURFACE TEXTURE = um MAX	COURSE / YEAR / GROUP	DATE 18/4/97 APPROVED DATE SCALE 2:1	SHEET No. No. OF SHEETS	DRAWING No. MRAR/001
	ALL DIMENSIONS IN MILLIMETERS		ANGLE PROJ.		

The component to manufacture was designed to include a wide range of turning operations. Several components were produced on a manual-centre lathe to prove out the design and manufacture before the actual experiment.

A feasible machining sequence was identified that included descriptions of the tasks necessary to produce the component. A checklist was prepared to provide the structure and content for the observation of actual sequences as carried out by the subjects. (Appendix C)

In the experiments, elements of the tasks were identified and corresponding mismatches were matched through observation. This entirely depended on how the subjects performed the experiment. Some of the tasks took place rather quickly so that close observation was essential. Confusion in interpreting types of mismatches was reduced because the elements of tasks had already been identified in the check list.

In the experiments, subjects were not restricted to follow the exact sequence of operations shown on the check list. A certain degree of freedom and flexibility was given to subjects so that the element of stress might be reduced or eliminated. Flexibility was permitted for example in terms of task sequencing. An example was the ordering of the taper turning and drilling tasks, which could be performed in either order . However, in normal circumstances, once a subject had chosen a task e.g. taper turning preceding drilling, than he would need to complete all the elements of taper turning before embarking on the drilling task. The objective of providing flexibility was to ensure that the tasks could be carried out in a way that reflected the subjects' preferences in real situations.

The matchings were recorded on the form shown in Appendix C.

Time to produce a component was not recorded. The purpose was to determine the number of mismatches committed by each subject and not the time taken to produce each component. Subjects might therefore try to avoid mismatches by working through the turning operations slowly.

5.8.1. Roles of the experimenter.

Throughout the machining and answering of questionnaires, the roles of the experimenter were :

a) to explain and clarify items in the questionnaires;
b) to give instructions before answering the questionnaires and performing the machining experiment;
c) to observe each element of the tasks carried out;
d) to detect the causes of the mismatches committed;
e) to understand each step of the machining procedure;
f) to make immediate decisions in categorising particular mismatches corresponding to relevant elements of the task.
g) to ignore errors caused by the machine as these were not within the scope of the study. Examples are errors due to defects in the machine or the component that would result in unacceptable tolerances or finishes.
h) to assist subjects particularly those from the unskilled category. The occurrence of assistance was recorded as a mismatch.

The experimenter is essentially required to categorise both the occurrence and causes of mismatches and thus must have considerable knowledge of the machining tasks. In this experiment the author acted as the experimenter and performed this role on the basis of previous experience and apprenticeship training.

5.8.2. The equipment for the experiment

Each experiment was carried out on site at the subject's own workplace on a familiar machine (restricted to manual centre lathes). Accuracy and speed of manufacture of the component were not under investigation as experimental variables and thus the use of different machines would not effect the results. Emphasis was solely on the number of mismatches committed by subjects. Prior to each test, it was ensured that the machine was free of pre-set tools.

Under normal circumstances, and like any other job, selection tasks e.g. selecting tools, speeds, accessories, etc was necessary before execution of the tasks could begin. Tools were not prearranged because the main purpose of the experiment was not to construct a laboratory type of experiment but rather an experiment with appropriate laboratory controls with the actual and realistic industrial environment in the background.

5.8.3. Accessories

Tools and other item available for turning operations included the following :

a) Micrometers (0-25mm), (25-50mm), (0-1 in) (for measuring diameters)
b) Keys and chuck : chuck key, allen keys, drill chuck
c) Knurling tool.
d) Drills through : 7.5 mm, 16.5 mm, 25mm
e) Reamer : 8mm, 14mm, 16mm.
f) Boring tool
g) Turning tool : butt-welded, inserts,
h) Grooving tool
i) Parting tool

5.8.4. Observation forms.

The content of the observation form was critically prepared and examined to provide the required features essential in the study. A well-organised observation form would increase reliability, reduce recording mismatches and ease the observer's task. The observation form is shown in Appendix C.

5.9. Questionnaire Survey

Questionnaires on operator performance in machining tasks and mismatches were given under control to the subjects. This is shown in Appendix D. Each subject was briefed on the instructions contained in the questionnaires. The questionnaires were answered immediately prior to and after performing the experimental task.

Subjects were asked to respond to the questionnaires based on their experience. It was emphasised that there were no right or wrong answers and that they should answer honestly. Subjects were assured of the confidentiality of individual responses. In contrast to the experiments, selection of responses to the questionnaire was carried out by the operators themselves. Throughout the period of filling in the questionnaire, subjects were not put under unnecessary stress. All the subjects were able to complete the questionnaires satisfactorily.

It was expected that by answering the questionnaire prior to performing turning operations subjects would provide responses based solely on their previous knowledge and experience. Reliability of the questionnaire and any influence from the immediate experience of producing a component could be counter-checked from the results of the questionnaire answered by subjects immediately after the turning operations.

5.9.1. The Questionnaire.

Items 1 to 27 consisted of unrelated categorical data i.e. the categories were discrete and could be placed in any order. There was neither an underlying linear scale nor units or intervals. The only possible score for each data item was its absence or presence.

Dichotomous responses, rating scales and ranking items were not used in the questionnaire. Instead, a multiple choice response was employed for each item because it provided :

a) a more efficient way to gather some types of information effectively.

b) respondents have less to read.

c) the questionnaire consumed less space.

d) mismatches should represent all possible choices.

e) appropriate use of nominal or categorical data.

Ordinal measurement was used for items 28 to 30. These categories are mutually exclusive and with no relationship between each other. Archial scaling was used for items 31 to 34.

5.9.2. Response bias

As in the case of any survey research, the potential of response bias in the sample is a concern. In order to examine the possibility of response bias, the characteristics of the participants were studied to identify any indications of such a bias. The demographics of the respondents are as shown in Table 5.3. From these characteristics of the participants and their distribution, it appeared that a wide range of participants was captured in the sample. As a result, the sample contains a reasonable representation of the target population, and difficulties with response bias should be reduced. Details of age and work experience are shown in Table 5.3.

5.9.3. Construction of instruments

i) Questionnaires items

The questionnaire was designed to cover various aspects relevant to the investigation:

a) Items 1-24 cover various tasks which offer choices of mismatches for selection. The choices stay the same for each task in question. The purpose was to facilitate determination of the frequency of mismatches committed and the types of mismatches most commonly occurring.

b) Item 25 covers reasons for the occurrences of mismatches. Reasons are endless to list and each reason is equally acceptable. However, the survey attempted to highlight the two most likely reasons for the occurrence of any mismatch.

Operators	Particulars	Minimum (years)	Mean (years)	Maximum (years)
Skilled	Age	22.5	41.9	57.5
	Work experience	2.5	20.6	27.5
Unskilled	Age	17.5	24.2	47.5
	Work experience	2.5	2.7	7.5
Skilled and unskilled combined	Age	17.5	34.3	57.5
	Working experience	2.5	12.9	27.5

Table 5.3 Age and work experience of the subjects

c) Item 26 covers the effects of mismatches on industrial production. The two most significant effects of mismatches were required from respondents.

d) Item 27 covers suggestions for preventing mismatches. The two most favoured suggestions were required from respondents.

e) Items 28-30 cover personal details of the respondents.

f) Item 31 covers self-confidence.

g) Item 32 covers level of trust.

h) Item 33 covers the overall levels of automation preferred.

i) Item 34 covers the levels of automation preferred for each particular task. Items 31, 32, 33 and 34 use a ten-point scale.

ii) Observation sheets for the field-based simulated experiment

The observation sheets were designed to cover all the tasks typical in manual turning operations against nine identified causes of mismatches. Typical manual turning operations included the following processes :

a) Facing-off
b) Drilling (7.5mm and 25mm diameter)
c) Reaming (8mm diameter)
d) Boring
e) Grooving | 4mm flat
f) Parting | tool
g) Chamfering

h) Selecting tools, speeds, feeds, etc. (reamers, drills, facing, sleeves, chucks)
i) Checking diamensions
j) Manual feeding of tools (25mm drill)
k) Taper turning
l) Set-up tools

5.10. Subjects

The two groups of subjects selected and recruited to perform the machining operations were :

a) skilled operators
b) unskilled operators (this category included those considered to be low-skilled or semi-skilled)

Some of the subjects in the skilled category were staff (technicians) of Loughborough and Nottingham Universities who volunteered without pay. Other skilled operators were recruited from local industry. The unskilled operator group consisted of college and university students who were paid volunteers. The students were from the departments of Manufacturing Engineering and Design Technology and all had some familiarity with machining gained from laboratory work or industrial placements.

Engineering students caused bias in the data because their motivation, attitude, career prospects, educational qualifications and mentality are very different compared to their counterparts, the apprentices and unskilled operators attached to industries. In particular, the subjective responses to the questionnaire survey might differ between students and the unskilled operators in industry. However, it is considered that in the objective part of the study (the experiments) the use of students does not lead to bias in the data. Students would be expected to be representative of the low and semi-skilled operators in unskilled machining performance and thus would commit similar mismatches, errors or mistakes as their counterparts in industry.

On the other hand, skilled operators have had considerable experience in turning operations in industries and they are fully representative of skilled performance in machining operations.

All selected operators were male and were identified by peer nominations or selected from candidates responding to advertisements. Based on the discussion above each group was considered (for the objective experiments) to be homogeneous and representative of the corresponding population under study.

5.11. Reliability and Validity

5.11.1. Reliability

In the HTMM method by experiment, observers could be regarded as instruments to establish the occurrence of mismatches. Observation of the occurrence of mismatches could suffer from bias or imprecision and errors could arise from variation within or between observers (Martin and Bateson, 1986). However, in this case a single observer was used and thus no errors could have arisen from this source.

Measures of intra-observer reliability (or observer consistency) establish the extent to which one particular observer obtained identical occurrences of mismatches from different observations of the same operations. In this study, intra-observer reliability was assessed by comparing the direct observations made with video recordings, and this is further discussed in Chapter Six.

In the HTMM questionnaire survey, the reliability of data was determined by the pre-test-post-test method. One questionnaire survey was completed by each subject prior to performing the experimental task and another by the same subject after performing the experiment.

5.11.2. Validity

The use of experiments and questionnaires in the HTMM method required validation so that results could confidently be extended to apply to the real world. Full validation would require large scale observation of operators performing their normal work tasks. This was considered to be outside the scope of this research, but some preliminary results and illustrations of the approach were obtained from a sample study conducted in industry.

The sample study comprised of observations on mismatches that occurred while an operator was at work on a manual centre lathe. The skilled operator, his machining tasks, the machine and industry were all picked at random. The observation was carried out for more than eight hours over a three-day period. Long hours of observation was necessary because each batch of work lasted for a considerable time. Generally, the observations covered most machining operations and the results of the case study are shown in Appendix E.

5.12. Assumptions

5.12.1. Assumptions in the field-based simulated experiment

a) The occurrence of mismatches were mutually exclusive (i.e. only one mismatch can occur at any one time). However, more than one mismatch could possibly occur, particularly if subjects make a series of mistakes or errors (one after another) in an element of a task.

b) The occurrence of mismatches were sequentially independent and are considered as random sequences. In fact the sequence, though variable, appeared to exhibit some degree of predictability. No attempt has been made to quantitatively establish the nature of this predictability, but some aspects of this are discussed in Chapter Seven.

5.12.2. Assumptions in the questionnaire survey.

a) Every subject responded in good faith to every item offered in both sets of the questionnaires before and after the experiment.
b) Prejudice did not arise among respondents.
c) There was an absence of personal ego.

5.13. **Data Analysis**

5.13.1. Introduction

Analysis of the data was carried out by means of non-parametric methods where the Mann-Whitney U, chi-square, Wilcoxon matched-pairs signed ranks tests and Spearman Correlation Coefficients were chosen. These tests were considered suitable for hypotheses testings and the association between two variables could be shown statistically.

Evaluation of man-machine systems must include both objective performance data and subjective participant data (Scallen et al, 1995). In this study, objective performance data was obtained from the total number and categories of mismatches committed by subjects during the machining trials. The subjective data from participants was collected from the questionnaire survey. Subjective psychophysical ranking (ranging from 1 as the lowest up to 10 as the highest) was used on variables involving self-confidence, level of trust, an overall level automation preferred and level of automation preferred for each human function (selection, setting-up and inspection).

5.13.2. Techniques

It has been observed that non-parametric tests (Martin and Bateson, 1986) such as the Mann-Whitney U tests, Wilcoxon matched-pairs sign rank tests, Chi-square and Spearman rank correlations are generally less powerful than the equivalent parametric tests for the following reasons :

a) they are free from the assumptions of parametric tests because they are more robust i.e. they are less dependent on various assumptions about normality for their validity.
b) non-parametric tests require only ranks, rather than measurement on an interval or ratio scale. Hence they can be used to analyse data measured on an ordinal scale.
c) the statistical power of many nonparametric tests is almost as great as that of the equivalent parametric test.

However the use of non-parametric tests is unavoidable in a study such as this due to the nature of human responses. The summary statistics used and the analysis undertaken must reflect the design of the study and the nature of the data. In a matched study, it is important to produce an estimate of the difference between matched pairs, and estimate the reliability of that difference. Analysis must take into account potential contaminating factors that might adversely influence the observed results.

The contaminating factors are :
a) test environments
b) backgrounds of the subjects
c) the difference between human error and mismatches
d) operators' self-reporting process.

5.13.3. Factors affecting data analysis

Three factors which affect methods of analysing data are :

i) The number of variables being examined :

Although there was a considerable number of variables involved in the study, systematic analysis was important to understand direct and related issues. In line with the statement of objectives and research hypotheses, either univariate or bivariate methods should be used to analyse the data. There were a range of techniques available for each univariate and bivariate method of analysis.

The following variables were examined in the study :

a) skill
b) age
c) working experience
d) frequency of mismatches
e) causes of mismatches
f) reasons for the occurrence of mismatches
g) effects of mismatches
h) self-confidence
i) trust
j) level of automation preferred

ii) Sample size

The techniques used were Mann-Whitney, Wilcoxon and Spearman Rank Correlation. In these methods small sample sizes are acceptable. Sixteen skilled and twelve unskilled operators were used for the experiments and questionnaires.

iii) Levels of measurement :

In this research, each variable was composed of two or more categories or attributes and these are as shown below :

a) Skill : skilled and unskilled (nominal variable)
This is a nominal variable which cannot be converted into a higher level (i.e. interval) variable. This was obtained by self-report in the questionnaire survey.

b) Age : <20, 20-<25, 25-<30, 30-<35, 35-<40, 40-<45, 45-<50, 50-55, >55 years. This is an ordinal variable which consists of numerical data. This was obtained by self-report in the questionnaire survey.

c) Working experience : <5, 5-<10, 10-<15, 15-<20, 20-<25, >25 years. This is an ordinal variable which consists of numerical data. This was obtained by self-report in the questionnaire survey.

d) The mismatches : (nominal variable) These are; assistance is sometimes required, omitting important step in the procedure, step performed incorrectly, repeat steps due to memory failure, a mistake or error in a request, repeating a procedure or step, wrong usage of a component, tool or instrument, wrong method applied to a task, and a step does not comply to normal procedure or standard guidelines.

The mismatches were self-reported in the questionnaire survey while in the experiments, they were identified by observation.

e) Sum of mismatches committed by subjects (interval variable). In both techniques, the questionnaire survey and observation of experiments, the sum of mismatches were computed.

f) Reasons for the occurrence of mismatches (ordinal variable). Suggested reasons offered for self-selection by the subjects in the questionnaire were : some operators are less knowledgable about machining tasks, careless mistakes, less well-trained operators, pressure to complete jobs on time.

g) Effects of mismatches (ordinal variable) were self-selected by subjects in the questionnaire survey. Suggested effects were : production delays, scrap work, loss of materials, loss of precious man-hours, loss of quality in production, no apparent effects on production and other possible effects.

h) The scale of self-confidence (interval variable) was in the range 1 to 10 and was self-selected by subjects in the questionnaire.

i) The scale of trust (interval variable) was in the range 1 to 10 and was self-selected by subjects in the questionnaire.

j) The scale of level of automation preferred (interval variable) was in the range 1 to 10 and was self-selected by subjects in the questionnaire.

A subject's score was computed by summing up the ratings across all the rating levels given. Scores could thus range from 10 to 100, with higher scores being indicative of high self-confidence, higher level of trust and preference for higher levels of automation. A similar method has been used to assess self-efficacy by numerous researchers (e.g. Gist and Mitchel, 1992, Bandura, 1984).

5.13.4. Statistical methods

Univariate and bivariate methods were used to analyse the data :

i) Univariate method :

This method provides information describing one characteristic of a sample at a time (de Vaus, 1995). The univariate method applied to the data was the histogram and it was expected that issues could be highlighted from an absolute perspective. Results from the sample are used to generalise the population under consideration. The variables involved are :

a) Reasons for the occurrences of mismatches.
b) Effects of mismatches
c) Suggestions for preventing mismatches

ii) Bivariate methods :

Simultaneous analysis of two variables to see how they are related is achieved by bivariate methods (de Vaus, 1995). This was expected to uncover further information concerning the behaviour of variables when compared with other variables. Variables involved are :

a) Variation of causes of mismatches (*from experiments*) with specific human characteristics (obtained from questionnaires) (self-confidence, level of trust, work experience and age) and with preferred levels of automation (obtained from the questionnaire survey).

b) Variation of causes of mismatches (*from questionnaire survey*) with specific human characteristics (obtained from questionnaires) (self-confidence, level of trust, work experience and age) and with preferred levels of automation (obtained from the questionnaire survey).

c) Variation of self-confidence with specific human characteristics (level of trust, work experience and age) all obtained from the questionnaire survey.

d) Variation of level of trust with specific human characteristics (work experience and age) all obtained from the questionnaire survey.

e) Variation of preferred levels of automation with specific human characteristics (self-confidence, level of trust, work experience and age) all obtained from the questionnaire survey.

Tests of the hypotheses were carried out to thereby reduce the uncertainties affected by the predictions. Techniques were used to check if there was consistency with the null hypotheses or if there were associations between two sets of scores.

5.14. Conclusion

The elaborate explanation of the HTMM method enables further understanding of the research design used in this study. Within the described limitations and weaknesses, the research design was successfully used to generate data and to provide empirical answers using the specified statistical techniques. Detailed analysis of the data is given in the next chapter.

CHAPTER 6

DATA ANALYSIS AND EMPIRICAL RESULTS

6.1. Introduction

This chapter describes the analysis of data, provides the results and concludes the findings of the research. The format is presented according to the order of objectives and hypotheses described in Chapter One (section 1.5) and Chapter Three respectively. The statistical techniques used in the analysis were Mann-Whitney, Wilcoxon-Match-pairs Ranks, Spearman Correlation Coefficient and Chi-square. Tables and graphs of results and a summary of findings are also provided.

Based on machining operations under investigations, analysis focused on the two groups of (a) combined skilled and unskilled operators and (b) skilled operators. The former group was intended to provide a picture of the broad spectrum of operators on the shopfloor while the later would provide a clear scenario of the actual situation with respect to the important sub-group of skilled operators.

Skilled operators are the products of industrial and apprenticeship systems. Operators who have reached specific skill levels attain a reputation on the shopfloor and command the respect of their colleagues. Problems related to tasks on the shopfloor are less likely to be associated with skilled operators, but because of this their shortcomings (if any) are worth investigating, for two reasons; firstly, because any common characteristics could indicate the source of difficulties. This would highlight the improvement to the design of tasks, machine design, operational support systems etc.; and secondly it would indicate how training for new staff should be organised to develop desirable characteristics.

Generally, industry has both skilled and unskilled operators. With respect to task functions, skilled operators are considered well-trained so that they should also generate the teaching (one to one basis) instructions, guidance and role models for unskilled operators. As such, skilled operators are important as they play two key roles i.e. performance of tasks to a high standard and the teaching of others. On the other hand, unskilled operators are the vulnerable group in that they could be influenced in terms of attitudes and skill by the skilled operators and in so doing help in the evolution of teaching and learning in industry.

Skilled and unskilled operators together might produce improved, modified and simpler works systems resulting from brainstorming sessions that might occur between them. Skilled operators have conventional methods, techniques and are rich in experience while the unskilled operators are an impatient breed who have different approaches to problem-solving. Undoubtedly the two groups have important roles to play and need to exist side-by-side to ensure constant and smooth generation of knowledge that is shared between skilled and unskilled operators. This would be an important contribution to progress and prosperity.

Unskilled operators may be considered "undeveloped" or immature with respect to the attainment of knowledge in machining operations. The main task for industry, and by far the most important, is to bring them out from the unskilled situations to achieve respectable skill levels.

6.2. Flow Chart of Data Organisation

The organisation of experimental and survey data is shown in the flowchart in Figure 6.1.

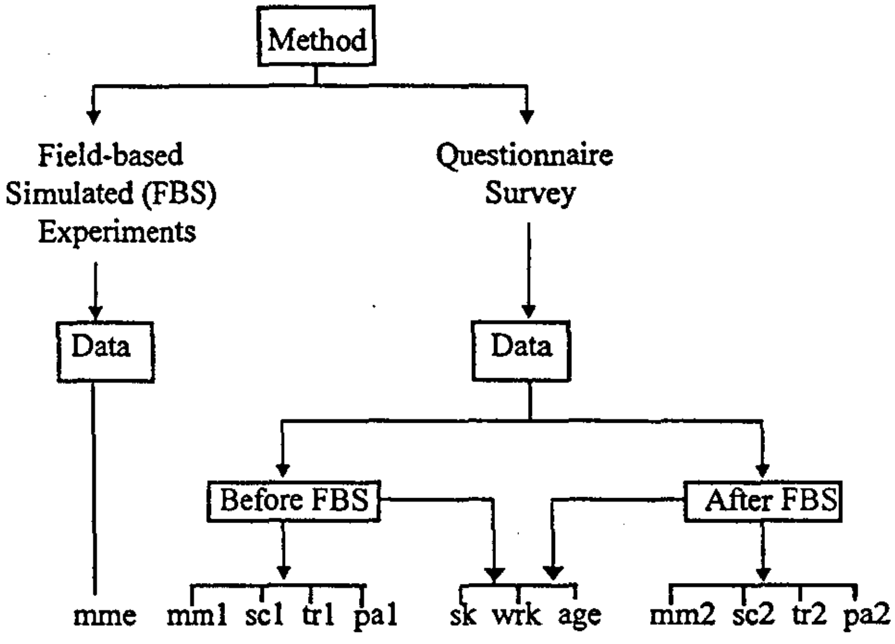


Figure 6.1 Flow chart showing the organisation of the variables used in the analysis.

Legend :

Abbre -viation	Variable	Collection technique
mme	mismatches	FBS experiments
mm1	mismatches	Questionnaires before FBS experiments
mm2	mismatches	Questionnaires after FBS experiments

sc1	self-confidence	Questionnaires before FBS experiments
sc2	self-confidence	Questionnaires after FBS experiments
tr1	trust	Questionnaires before FBS experiments
tr2	trust	Questionnaires after FBS experiments
pa1	preferred automation	Questionnaires before FBS experiments
pa2	preferred automation	Questionnaires after FBS experiments
sk	skill	Questionnaires before/after FBS experiments
wrk	work experience	Questionnaires before/after FBS experiments
age	age	Questionnaires before/after FBS experiments

Referring to Figure 6.1, tests involving mismatches (mme) and skill (sk) and mismatches (mm1 and mm2) and skill (sk) are analysed to establish any relationships between them using Mann-Whitney U tests. Similar tests are carried out between the variables for the selection, set-up and inspection functions. Results would indicate whether mismatches depend on the skill categories of operators or not.

Based on mismatches (mme, mm1 and mm2) and skill (sk) independence between particular mismatches and categories of operators is investigated using chi-square tests to establish whether the occurrence of particular mismatches depends on the categories of operators.

Tests for correlation between mismatches (mme) and mismatches (mm1 and mm2) are carried out on both skilled and unskilled operators. The aim of the tests is to establish if correlation exists between the experimental and questionnaire mismatches.

The questionnaire survey produced two sets of mismatches (mm1 and mm2) for each subject and there is a need to test for any differences between these two. The aim was to establish if the FBS experiment had had any effect on the results.

Further tests using Spearman correlations are carried out between mismatches (mm1 and mm2) and mismatches (mme) to determine which questionnaire most closely corresponded to the FBS experiment. The mismatches (mm1 and mm2) showed significant differences and thus could be considered as being unreliable for use in further analysis. Hence all subsequent testing of hypotheses are carried out using the results from FBS experiments (mme).

With respect to the selection, set-up and inspection functions the mismatches (mm1 and mm2) are analysed to establish whether there are any differences between mismatches for each function. The aim was to determine variations between the functions for both skilled and unskilled operators. Tests are also carried out for the relationships between mismatches (mm1 and mm2) and skill (sk) of operators for the respective functions.

Unlike mismatches (mme), experimental data on self-confidence (sc1 and sc2), trust (tr1 and tr2) and preferred levels of automation (pa1 and pa2) does not exist and thus the results from the questionnaire survey are used in subsequent analyses. As this involves questionnaire data produced both before and after the FBS experiments, tests are carried out to determine if there are any differences between each pair of data. Mean values are used in subsequent analyses if no differences exist, otherwise data from the questionnaire after the FBS experiment is used.

Tests of hypotheses are carried out using the following variables :

Hypothesis 1 : Mismatches (mme) and skill (sk)

Hypothesis 2 : Mismatches (mme) and self-confidence (mean of sc1 and sc2).

Hypothesis 3 : Mismatches (mme) and trust (mean of tr1 and tr2).

Hypothesis 4 : Mismatches (mme) and work experience (wrk).

Hypothesis 5 : Mismatches (mme) and age.

Hypothesis 6 : Self confidence (mean of sc1 and sc2) and skill (sk).

Hypothesis 7 : Self confidence (mean of sc1 and sc2) and trust (mean of tr1 and tr2).

Hypothesis 8 : Self-confidence (mean of sc1 and sc2) and work experience (wrk).

Hypothesis 9 : Self-confidence (mean of sc1 and sc2) and age.

Hypothesis 10 : Trust (mean of tr1 and tr2) and skill (sk).

Hypothesis 11 : Trust (mean of tr1 and tr2) and work experience (wrk).

Hypothesis 12 : Trust (mean of tr1 and tr2) and age.

Hypothesis 13 : Preferred levels of automation (pa2) and mismatches (mme).

Hypothesis 14 : Preferred levels of automation (pa2) and skill (sk).

Hypothesis 15 : Preferred levels of automation (pa2) and self-confidence (mean of sc1 and sc2)

Hypothesis 16 : Preferred levels of automation (pa2) and trust (mean of tr1 and tr2)

Hypothesis 17 : Preferred levels of automation (pa2) and work experience (wrk).

Hypothesis 18 : Preferred levels of automation (pa2) and age.

6.3. Mean Scale Values.

The scale values of self confidence recorded by each subject was used to establish the overall mean scale value (MSV) for both groups of subjects i.e. skilled and unskilled operators. The mean scale value is simply the sum of values recorded for all subjects divided by the total number of subjects.

For example, from the questionnaire survey it was found that skilled operators have an overall MSV of 8.5 for self-confidence in turning operations. The overall mean scale values of trust and preferred level of automation were determined in a similar fashion.

6.4. First Objective : Relationships between mismatches and human characteristics.

6.4.1. Mismatches and skill

Hypothesis 1 : The higher the skill level of operators, the fewer mismatches are committed.

A study was carried out to establish the relationship between mismatches and skill with the objective of determining the effect and extent of mismatches committed by different skill categories of operators in machining operations on manual centre lathes. Variations and relationships between variables were determined quantitatively (based on field-based simulated (FBS) experiments) and qualitatively (based on questionnaire surveys before and after the FBS experiments).

6.4.1.1. Field-based Simulated Experiment

The field-based simulated experiment using the Human-Task Mismatch Matching method provided data on mismatches generated by subjects as they performed machining operations. These are shown in Appendix F1 and F2.

a) Test for the relationships between mismatches (FBS experiments) and skill categories of operators (skilled and unskilled).

The scores of mismatches are analysed using the Mann-Whitney technique to establish whether there could be a relationship between the categories of operators (i.e. skilled and unskilled) and mismatches committed.

Mann-Whitney U test is used (Siegel, 1956) :
n1 = 16, R1 = 140.5, U1 = 187.5
n2 = 12, R2 = 265.5, U2 = 4.5,
From Table 6.1, For 9 < n1 > 20 and using Table K, U2 = 4.5 < Ucrit. = 31, H_0 may be rejected at the level of significance of alpha = 0.002 (a Two-tailed test) in favour of H_1. Hence, there is a relationship between mismatches and categories of skill of operators with respect to machining operations.

Subjects	Occurrence of Mismatches	Rank
1	15	14.0
2	7	7.5
3	7	7.5
4	16	15.0
5	5	4.0
6	13	11.0
7	9	10.0
8	8	9.0
9	20	17.0
10	14	12.5
11	5	4.0
12	19	16.0
13	5	4.0
14	6	6.0
15	4	2.0
16	3	1.0
Total	156	R1=140.5
17	130	28.0
18	21	18.0
19	41	23.0
20	34	20.0
21	50	27.0
22	37	21.5
23	46	25.0
24	27	19.0
25	37	21.5
26	48	26.0
27	14	12.5
28	43	24.0
Total	528	R2=265.5

Table 6.1. Mismatches by skilled and unskilled operators.
(Subjects : 1-16 skilled, 17-28 unskilled)

b) Test for the relationship and independence between particular mismatches and categories of operators

This test is to establish whether particular mismatches occur dependent on the operators skill category. Refering to Figure 6.1 the variables involved are skill (sk) and mismatches from the FBS experiment (mme).

The occurrences for each particular mismatch for both skilled and unskilled operators were obtained and tabulated as shown in Table 6.2. The occurrences are compared between skilled and unskilled operators.

Mismatches	Skilled Operators	Unskilled Operators
1. Intrusion	5	306
2. Omission	6	27
3. Commission	4	37
4. Reversal in sequence	8	7
5. Wrong request	1	3
6. Repetition	112	83
7. Acts on Wrong components	12	27
8. Misapplication	0	13
9. Violations	8	25
10. Other causes	0	0
Total	156	528

Table 6.2. Occurrence of mismatches (as observed from the FBS experiments) for skilled operators (n=16) and unskilled operators (n=12).

It is observed from Table 6.2 that "repeating steps" predominates for skilled operators, while "assistance is sometimes required" predominates for unskilled operators.

i) Chi-square Analysis of Category of Mismatches (from FBS experiments) and Category of operators

Chi-square analysis was used to test for independence between skill categories of operators and categories of mismatches. This is shown in Table 6.3 where the result indicates that a significant value has been obtained. The legend of the table shows re-grouping of mismatches (Groups A, B, C, D, E and F) to provide at least five mismatches for each cell in the analysis.

Category of mismatches	Skilled Operators	Unskilled Operators	Row/Total
A	6	309	315 / 46.1%
B	6	27	33 / 4.8%
C	4	37	41 / 6.0%
D	120	90	210 / 30.7%
E	12	40	52 / 7.6%
F	8	25	33 / 4.8%
Column / Total	156 / 22.8%	528 / 77.2%	684 / 100%

Chi-Square	Value	DF	Significance
Pearson	223.20712	5	.00000

Minimum Expected Frequency - 7.526

Legend :

Group	Mismatches
Category A :	Assistance is sometimes required (1) A mistake or error in request (5)
Category B :	Important step is left out (2)
Category C :	A step is performed incorrectly (3)
Category D :	A series of steps need to be repeated due to memory lapse (4) A procedure or step is repeated several times (6)
Category E :	Wrong usage of a component, a tool or an instrument (7) Wrong method is applied in a task (8)
Category F :	Step does not comply to normal procedure or standard guidelines (9) Other mismatches (11)

Table 6.3 Test for independence between the occurrence of particular mismatches (from FBS experiments) and skill categories of operators. (Refer to data in Table 6.2).

Tobt = 223.2 > Tcri.= 20.52 at alpha = 0.001. H_o is rejected in favour of H_1. The result is significant at alpha=0.001 and suggests that the occurrence of mismatches depends on the skill categories of operators with respect to machining operations in field-based simulated experiments.

ii) Relationships between mismatches and skill for selection, set-up and inspection functions.

Task analysis provided the elements essential in machining to produce the sample component. Based on the nature of the task elements these were categorised into the three identified human functions i.e. selection, set-up and inspection functions as shown in Appendix C.

From the observation sheets in the FBS experiments, the occurrences of each particular set of mismatches were obtained for the identified human function and are shown in Table 6.4. Mann-Whitney U Test techniques were used to test relationships between mismatches and skill with respect to each function i.e. selection, set-up and inspection.

Analysis by Mann-Whitney U Test :

From Table 6.4, For the selection functions,
n1 =16, R1 = 144, U1 = 184, n2 = 12, R2 = 262, U2 = 8
For 9 < n1 > 20 and using Table K, U2 = 8 < Ucrit. = 31, H_o may be rejected at the level of significance of alpha = 0.002 (a Two-tailed test) in favour of H_1. Hence, there is a relationship between mismatches and categories of skill with respect to selection functions.

For the set-up functions : n1=16, R1=141.5, U1=186.5, n2=12, R2=264.5, U2=5.5

For 9 < n1 > 20 and using Table K, U2 = 5.5 < Ucrit. = 31, H_0 may be rejected at the level of significance of alpha = 0.002 (a Two-tailed test) in favour of H_1. Hence, there is a relationship between mismatches and categories of skill with respect to set-up functions.

Subject	Selection	Rank	Set-up	Rank	Inspection	Rank
1	7	13.0	6	11.0	2	20.0
2	3	5.5	4	9.5	0	6.0
3	4	8.5	3	7.0	0	6.0
4	9	16.0	7	13.0	0	6.0
5	2	3.0	3	7.0	0	6.0
6	3	5.5	9	16.5	1	14.5
7	7	13.0	2	4.5	0	6.0
8	5	11.0	2	4.5	1	14.5
9	9	16.0	10	18.0	1	14.5
10	4	8.5	8	15.0	2	20.0
11	1	1.0	3	7.0	1	14.5
12	12	20.0	7	13.5	0	6.0
13	4	8.5	1	2.5	0	6.0
14	2	3.0	4	9.5	0	6.0
15	4	8.5	0	1.0	0	6.0
16	2	3.0	1	2.5	0	6.0
Total	78	144.0	70	141.5	8	158.0
17	32	28.0	85	28.0	13	28.0
18	10	18.5	9	16.5	2	20.0
19	15	22.5	20	22.0	6	25.0
20	10	18.5	22	23.0	2	20.0
21	15	22.5	29	27.0	6	26.0
22	17	25.0	18	20.0	2	20.0
23	19	26.0	24	24.5	3	23.0
24	9	16.0	17	19.0	1	14.5
25	13	21.0	19	21.0	5	24.0
26	16	24.0	25	26.0	7	27.0
27	7	13.0	7	13.0	0	6.0
28	19	27.0	23	24.5	1	14.5
Total	182	262.0	298	264.5	48	248.5

Table 6.4. Occurrence of mismatches (as observed from FBS experiments) for the selection, set-up and inspection functions (Skilled operators : Subjects 1-16, Unskilled operators : Subjects 17-28).

For inspection functions :

$n1 = 16, R1 = 158, U1 = 170,\ n2 = 12, R2 = 248, U2 = 22$

For $9 < n1 > 20$ and using Table K, $U2 = 22 < Ucrit. = 31$, H_0 may be rejected at the level of significance of alpha = 0.002 (a Two-tailed test) in favour of H_1. Hence, there is a relationship between mismatches and categories of skill with respect to inspection functions.

In summary, based on Mann-Whitney tests, all the three identified human functions recorded relationships between mismatches and skill in turning operations.

6.4.1.2. Questionnaire Survey.

a) Occurrence of Mismatches

Mismatches	Skilled Operators (Qbefore)	Skilled Operators (Qafter)	Unskilled Operators (Qbefore)	Unskilled Operators (Qafter)
1. Intrusion	42	28	134	100
2. Omission	7	6	15	9
3. Commission	57	22	67	37
4. Reversal in sequence	29	26	35	27
5. Wrong request	16	6	10	6
6. Repetition	107	79	25	34
7. Acts on wrong component	43	26	34	17
8. Mis-applications	48	43	57	34
9. Violations	52	27	30	18
10.Others	13	26	19	25
Total	414	289	426	307

Table 6.5. Mismatches Obtained from Questionnaire Surveys.

(QBefore : Questionnaires before FBS experiments, QAfter : Questionnaires after FBS experiments)

Mismatches for skilled and unskilled operators obtained from the questionnaire surveys are categorised in Table 6.5. More detailed break-downs of the mismatches are shown in Tables F3, F4, F5 and F6 in Appendix F.

From Table 6.5, for both the questionnaire survey before and after the FBS experiments, it was found that "a procedure or step is repeated several times" is the most frequent mismatch and "an important step in the procedure is left out" is the least frequent mismatch for skilled operators. For unskilled operators, it was found that "assistance is sometimes required" is the most frequent and "a mistake or error in a request for a certain item" is the least frequent.

b) Chi-square test for independence between particular mismatches and skill.

Category of Mismatches	Skilled Operators	Unskilled Operators	Total
1	42	134	176 /21.0%
2	7	15	22 / 2.6%
3	57	67	124 /14.8%
4	29	35	64 / 7.6 %
5	16	10	26 / 3.1%
6	107	25	132 /15.7%
7	43	34	77 / 9.2 %
8	48	57	105 /12.5%
9	52	30	82 / 9.8%
10	13	19	32 / 3.8%
Total	414 / 49.3%	426 / 50.7%	840 /100%

Table 6.6 Test for independence between the occurrence of particular mismatches (from questionnaire survey before the FBS experiments) and categories of skill of operators. (Refer to data in Table 6.5)

Independence between the categories of mismatches (based on Table 6.5) and skill categories of operators were analysed using chi-square methods. These are shown in Table 6.6 and 6.7.

Chi-Square	Value	DF	Significance
Pearson	113.39549	9	.00000

Minimum Expected Frequency - 10.843

Tobt = 113.39549 > Tcri.= 27.88 at alpha = 0.001. H_0 is rejected in favour of H_1. The result from the questionnaire survey before the FBS experiment is significant. This suggests that the occurrence of mismatches depends on the skill categories of operators.

Category of Mismatches	Skilled Operators	Unskilled Operators	Total
1	28	100	128 (21.5%)
2	6	9	15 (2.5%)
3	22	37	59 (9.9%)
4	26	27	53 (8.9%)
5	6	6	12 (2.0%)
6	79	34	113 (19.0%)
7	26	17	43 (7.2%)
8	43	34	77 (12.9%)
9	27	18	45 (7.6%)
10	26	25	51 (8.6%)
Total	289 (48.5%)	307 (51.5%)	596 (100.0%)

Table 6.7 Test for independence between the occurrence of particular mismatches (from questionnaire survey after the FBS experiments) and categories of skill of operators. (Refer to data in Table 6.5).

Chi-Square	Value	DF	Significance
Pearson	67.12566	9	.00000

Minimum Expected Frequency - 5.819

Tobt = 67.12566 > Tcri.= 27.88 at alpha = 0.001. H_0 is rejected in favour of H_1. The result from the questionnaire survey after the FBS experiment is significant. This suggests that the occurrence of mismatches depends on the skill categories of operators.

c) Correlation between the categories of mismatches from FBS experiments and questionnaires survey.

Tests for correlation are carried out between the categories of mismatches from FBS experiment (Table 6.2) (mme shown in Figure 6.1) and mismatches (Table 6.6) from the questionnaire survey before FBS experiment (mm1 in Figure 6.1) and that after FBS experiment (mm2 in Figure 6.1). Tests are conducted between the variables to establish any difference in results obtained from the two techniques (i.e. FBS experiment and questionnaire survey).

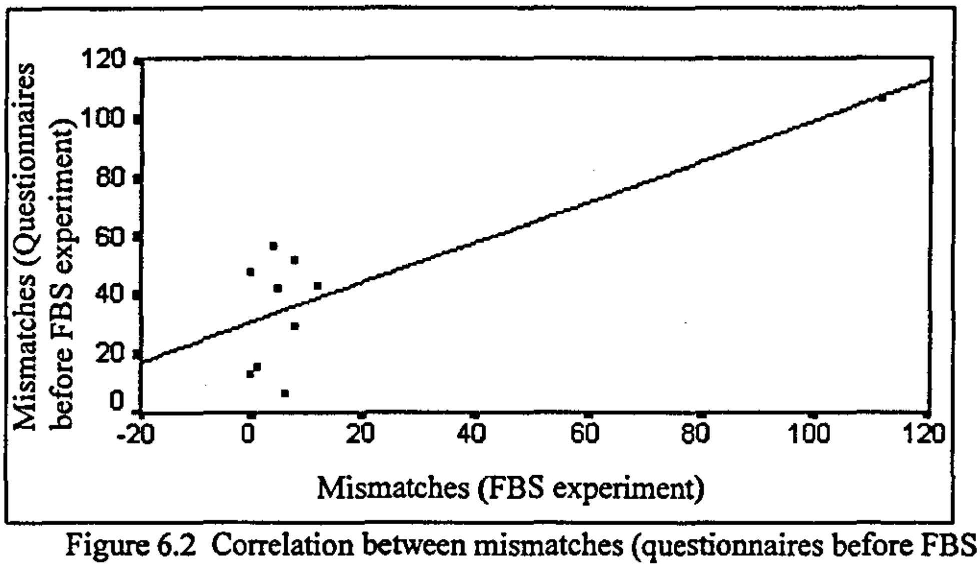


Figure 6.2 Correlation between mismatches (questionnaires before FBS experiment) and the FBS experiment for skilled operators.

From Figure 6.2, the result indicates that the correlation between mismatches (FBS experiments) and mismatches (questionnaire before FBS experiment) for skilled operators is Rs = 0.3781, significant at alpha = 0.281 level (a Two-tailed test). Thus we fail to reject H_0 and conclude that mismatches (FBS experiment) and mismatches (questionnaire before FBS experiment) are not correlated.

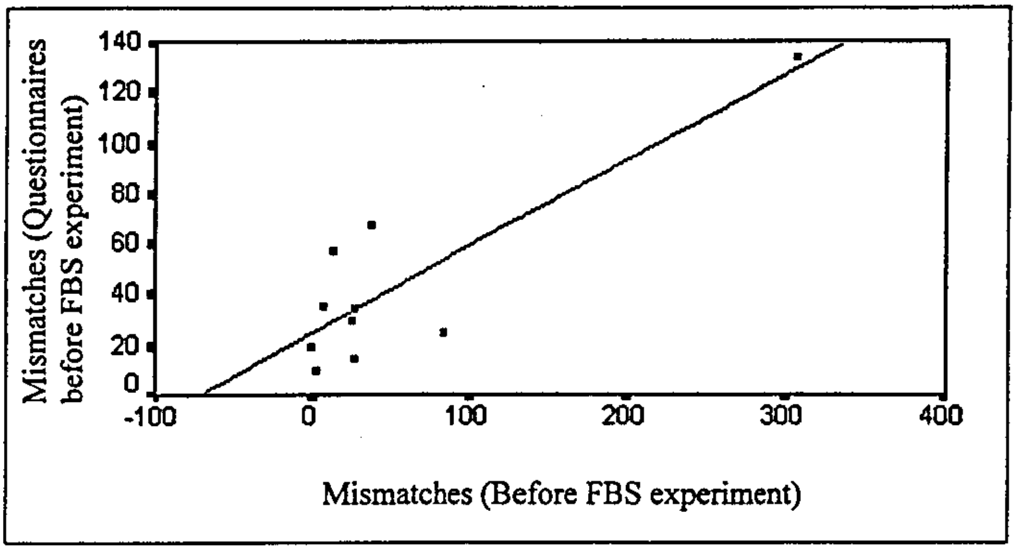


Figure 6.3 Correlation between mismatches (questionnaires before FBS experiment) and FBS experiment for unskilled operators

From Figure 6.3, the result indicates that the correlation between mismatches (FBS experiments) and mismatches (questionnaire before FBS experiment) for unskilled operators is Rs = 0.4924, significant at alpha = 0.148 level (a Two-tailed test). Thus we fail to reject H_0 and conclude that mismatches (FBS experiment) and mismatches (questionnaire before FBS experiment) are not correlated.

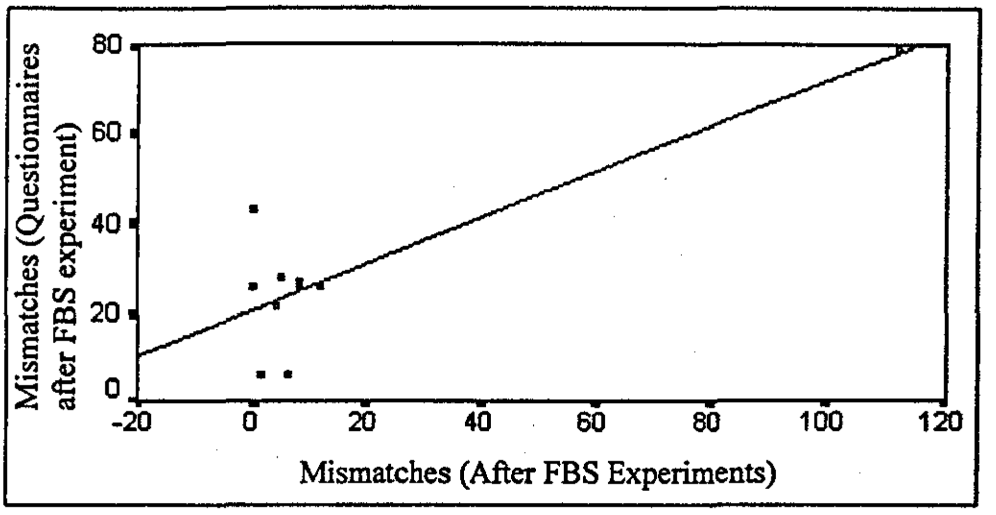


Figure 6.4 Correlation between mismatches (questionnaires after FBS experiment) and FBS experiment for skilled operators

From Figure 6.4, the result indicates that the correlation between mismatches (FBS experiments) and mismatches (questionnaire after FBS experiment) for skilled operators is Rs = 0.2353, significant at alpha = 0.513 level (a Two-tailed test). Thus we fail to reject H_0 and conclude that mismatches (FBS experiment) and mismatches (questionnaire after FBS experiment) are not correlated.

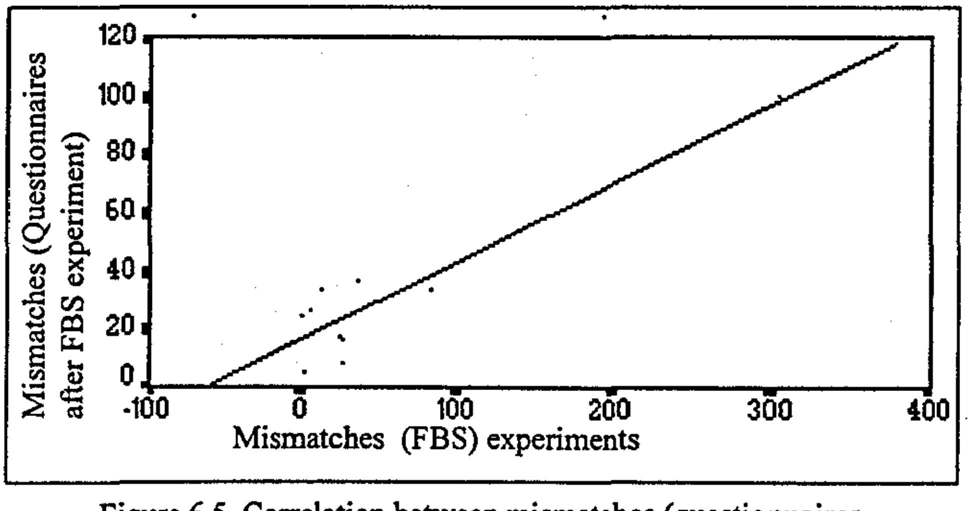


Figure 6.5 Correlation between mismatches (questionnaires after FBS experiment) and FBS experiment for unskilled operators

From Figure 6.5, the result indicates that the correlation between mismatches (FBS experiments) and mismatches (questionnaire after FBS experiment) for unskilled operators is Rs = 0.5427, significant at alpha = 0.105 level (a Two-tailed test). Thus we fail to reject H_0 and conclude that mismatches (FBS experiment) and mismatches (questionnaire after FBS experiment) are not correlated.

Based on the above tests, there is evidence that skilled operators are less able to estimate their own performance when compared with unskilled operators. By and large, the results show that mismatches have very low and insignificant correlations with performance. The estimates of mismatches provided by questionnaire responses are unreliable. Hence the use of mismatches obtained from the FBS experiment. However, results obtained from the questionnaire after the FBS experiment are used for the variables not established by experiments (i.e. self-confidence, level of trust and preferred levels of automation) because it is expected that operator responses are derived from the FBS experiment since they were given immediately after the experiments.

d) Differences between Mismatches obtained from Questionnaires before and after the FBS Experiments using the Wilcoxon Technique

The occurrences of mismatches obtained from questionnaire surveys were tested to establish if there was any difference between those that occurred before the FBS experiments and those that occurred afterwards. The variables involved are shown in Figure 6.1 i.e. mismatches before FBS experiment (mm1) and mismatches after FBS experiment (mm2). Details of the analysis are shown in Tables 6.8 and 6.9.

From Table 6.8 and by Wilcoxon matched-pairs signed ranks test, Tobt.=11<Tcrit.=21, at alpha=0.05 for a Two-tailed test. The result is significant and therefore H_0 is rejected in favour of H_1. The analysis indicates that there is a difference in the occurrence of mismatches before and after FBS experiments for skilled operators.

ubject	Before FBS expt	After FBS expt.	Diff.	Rank	Signed Rank	Sum +ve	Sum -ve
1	9	3	-6	8.0	-8.0		-8.0
2	10	7	-3	4.5	-4.5		-4.5
3	54	51	-3	4.5	-4.5		-4.5
4	15	10	-5	8.0	-8.0		-8.0
5	18	12	-6	8.0	-8.0		-8.0
6	9	7	-2	3.0	-3.0		-3.0
7	0	0	0				
8	0	0	0				
9	30	43	13	11.0	11.0	11.0	
10	72	21	-51	14.0	-14.0		-14.0
11	1	0	-1	1.5	-1.5		-1.5
12	52	36	-16	12.0	-12.0		-12.0
13	43	37	-6	8.0	-8.0		-8.0
14	54	22	-32	13.0	-13.0		-13.0
15	22	21	-1	1.5	-1.5		-1.5
16	25	19	-6	8.5	-8.0		-8.0
Total	414	289				11.0	94.0

Table 6.8. Occurrences of Mismatches by Skilled Operators before and after the FBS experiment.

From Table 6.9, by Wilcoxon matched-pairs signed ranks Test, Tobt = 4<Tcrit. =14 at alpha = 0.05 for a Two-tailed test. The result is significant and therefore H_o is rejected in favour of H_1. The analysis indicates that there is a difference in the occurrence of mismatches before and after FBS experiments for unskilled operators.

Subject	Before FBS expt.	After FBS expt.	Diff.	Rank	Signed Rank	Sum +ve	Sum -ve
1	6	2	-4.0	4	-4		-4
2	28	29	1.0	1	1	1	
3	19	10	-9.0	7	-7		-7
4	32	13	-19.0	10	-10		-10
5	60	54	3.0	3	3	3	
6	27	17	-10.0	8	-8		-8
7	45	24	-21.0	11	11		-11
8	47	34	-13.0	9	9		-9
9	71	48	-23.0	12	12		-12
10	19	13	-6.0	5	5		-5
11	51	44	-7.0	6	6		-6
12	21	19	-2.0	2	2		-2
Total	426	307				4	74

Table 6.9. Occurrences of Mismatches by unskilled operators.

e) Correlation of questionnaire results with the FBS experiments (analysis using Spearman correlations)

An analysis is required to determine which of the questionnaires (before or after the FBS experiment) is closest to the experimental results. The variables involved are shown in Figure 6.1 i.e. mismatches before FBS experiment (mm1), mismatches after FBS experiment (mm2) and mismatches from FBS experiment (mme). Table 6.10 shows the score of occurrence of mismatches from the questionnaire surveys and field-based simulated experiments.

Subject	Questionnaires before FBS expt.	Questionnaires after FBS expt.	FBS expt.
1	9	3	15
2	10	7	7
3	54	51	7
4	15	10	16
5	18	12	5
6	9	7	13
7	0	0	9
8	0	0	8
9	30	43	20
10	72	21	14
11	1	0	5
12	52	36	19
13	43	37	5
14	54	22	6
15	22	21	4
16	25	19	3
17	6	2	130
18	28	29	21
19	19	10	41
20	32	13	34
21	60	54	50
22	27	17	37
23	45	24	46
24	47	34	27
25	71	48	37
26	19	13	48
27	51	44	14
28	21	19	43

Table 6.10 Mismatches obtained from questionnaires survey and FBS experiments (1-16 : Skilled operators, 17-28 : Unskilled operators)

Analysis using Spearman correlations shows that the questionnaire survey after the FBS experiments has the higher correlation with the experimental results. Therefore, data obtained by questionnaires after the FBS experiments are used in the analysis if there is a difference between the questionnaires before and after the FBS experiments. If there is no difference between the questionnaires before and after the FBS experiments, the mean values of the variables are used for the subsequent analysis.

f) Correlations between mismatches (Questionnaires) and mismatches (FBS experiments) for skilled and unskilled operators

Spearman correlation coefficient analysis is applied to the frequency of mismatches obtained from the questionnaire surveys and from the FBS experiments. (Refer Figure 6.6 and 6.7)

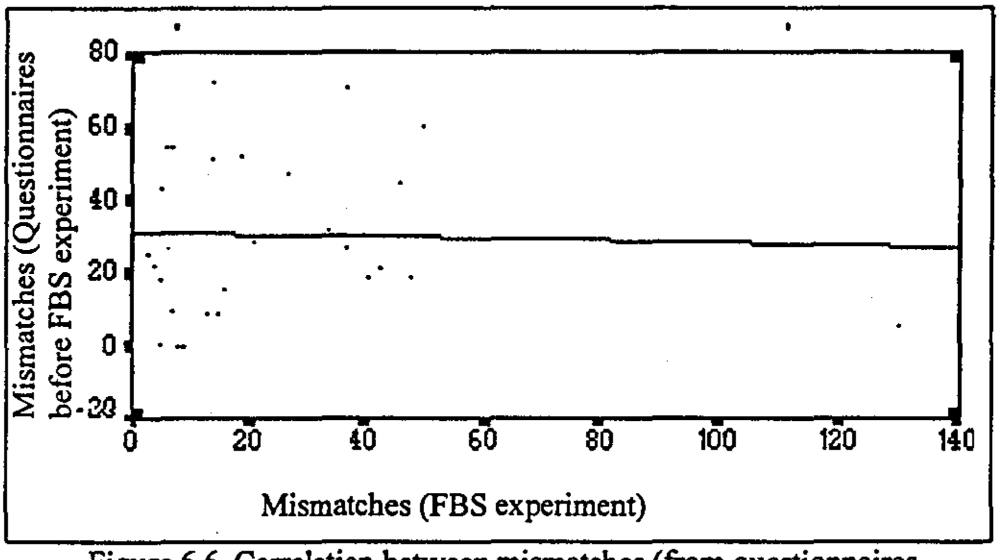


Figure 6.6 Correlation between mismatches (from questionnaires before the FBS experiment) and from the FBS experiment.

From Figure 6.6, the result indicates that the correlation between mismatches (FBS experiments) and mismatches (questionnaires before FBS experiment) is Rs=0.1616, significant at alpha=0.411 level (a Two-tailed test). Thus we fail to reject H_0 and conclude that mismatches (FBS experiment) and mismatches (questionnaires before FBS experiment) are not correlated for skilled and unskilled operators.

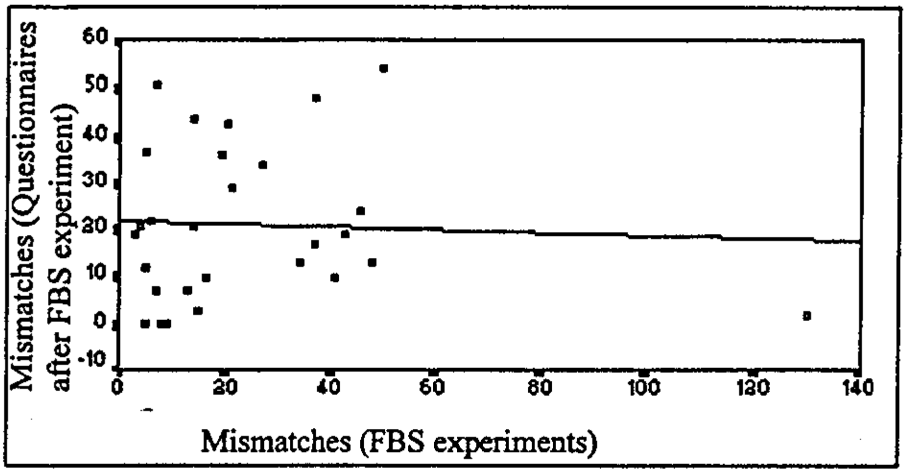


Figure 6.7 Correlation between mismatches (from questionnaires after the FBS experiment) and from the FBS experiment.

From Figure 6.7, the result indicates that the correlation between mismatches (FBS experiments) and mismatches (questionnaires after FBS experiment) for skilled operators is Rs = 0.2353, significant at alpha = 0.513 level (a Two-tailed test). Thus we fail to reject H_0 and conclude that mismatches (FBS experiment) and mismatches (questionnaires after FBS experiment) are not correlated for skilled and unskilled operators.

g) Relationships between mismatches (from questionnaires before and after FBS experiments) and skill using Mann-Whitney U Rank Test analysis.

The occurrences of mismatches obtained from questionnaire surveys were tested to establish if there was any relationship between mismatches and the skill category of operators. The variables involved are shown in Figure 6.1 i.e. mismatches from questionnaires before FBS experiment (mm1), mismatches from questionnaires after FBS experiment (mm2) and skill categories of operators (sk). Details of the analysis are shown in Tables 6.11 and 6.12.

Subject	Mismatches before FBS expt.	Rank	Mismatches after FBS expt.	Rank
1	9	5.5	3	5.0
2	10	7.0	7	6.5
3	54	24.5	51	27.0
4	15	8.0	10	8.5
5	18	9.0	12	10.0
6	9	5.5	7	6.5
7	0	1.5	0	2.0
8	0	1.5	0	2.0
9	30	17.0	43	24.0
10	72	28.0	21	17.0
11	1	3.0	0	2.0
12	52	23.0	36	22.0
13	43	19.0	37	23.0
14	54	24.5	22	18.0
15	22	13.0	21	16.0
16	25	14.0	19	14.5
Total	414	204.0	289	204.0
17	6	4.0	2	4.0
18	28	16.0	29	20.0
19	19	10.5	10	8.5
20	32	18.0	13	11.5
21	60	26.0	54	28.0
22	27	15.0	17	13.0
23	45	20.0	24	19.0
24	47	21.0	34	21.0
25	71	27.0	48	26.0
26	19	10.5	13	11.5
27	51	22.0	44	25.0
28	21	12.0	19	14.5
Total	426	202.0	307	203.0

Table 6.11. Occurrences of Mismatches before and after the FBS Experiments.

(Subjects : skilled (1-16), unskilled (17-28))

Analysis by Mann-Whitney U Rank Test

From Table 6.11, For mismatches before FBS experiments,

n1 = 16, R1 = 204, U' = 124, n2 = 12, R2 = 204.5, U = 68
Since Uobt. = 68 > Ucrt. = 53 at alpha = 0.05 (for a Two-tailed Test), the result is non-significant and fails to reject H_o. Therefore, there is no relationship between mismatches and skill before the FBS experiments.

For mismatches after FBS experiments,
n1 = 16, R1 = 204, U' = 124, n2= 12, R2 = 202, U = 68
Since Uobt. = 68 > Ucrit. = 41 at alpha = 0. 05 (for a Two-tailed Test), the result is non-significant and fails to reject H_o. Therefore, there is no relationship between mismatches and skill after the FBS experiments.

h) Differences between the occurrence of mismatches before and after the FBS experiments using the Wilcoxon technique.

i) Selection functions

The variables involved are mismatches that have occurred in selection functions.

From Table 6.12, by Wilcoxon matched-pairs signed ranks Test, (n=14). Tobt.=8.5 < Tcrit. = 30 at alpha = 0.05 for a Two-tailed test. The result is significant and therefore H_o is rejected in favour of H_1. There is a difference between the occurrence of mismatches in the selection functions between that occurring before the FBS experiments and that occurring after the FBS experiments for skilled operators.

From Table 6.13, by Wilcoxon matched-pairs signed ranks Test, n=10. Tobt.=7.5<Tcrit.=14.0 at alpha=0.05 for a Two-tailed test. The result is significant and therefore H_o is rejected in favour of H_1. There is a difference between the occurrence of mismatches in selection before the FBS experiments when compared to mismatches after the experiments for unskilled operators.

Subject	Qbef	Qaft	Diff.	Rank	Sign Rank	Sum +ve	Sum -ve
1	3	0	-3	5.5	-5.5		-5.5
2	5	4	-1	2.0	-2.0		-2.0
3	24	19	-5	11.0	-11.0		-11.0
4	7	4	-3	5.5	-5.5		-5.5
5	6	3	-3	5.5	-5.5		-5.5
6	6	3	-3	5.5	-5.5		-5.5
7	0	0	0				
8	0	0	0				
9	13	17	4	8.5	8.5	8.5	
10	23	6	-17	14.0	-14.0		-14.0
11	1	0	-1	2.0	-2.0		-2.0
12	20	19	-1	2.0	-2.0		-2.0
13	17	13	-4	8.5	-8.5		-8.5
14	21	8	-13	13.0	-13.0		-13.0
15	14	9	-5	11.0	-11.0		-11.0
16	14	9	-5	11.0	-11.0		-11.0
Total	176	114				8.5	96.5

Table 6.12 Occurrences of mismatches for human selection functions for skilled operators (n=14)

Subject	Qbef	Qaft	Diff.	Rank	Signed Rank	Sum +ve	Sum -ve
1	4	1	-3.0	2.5	-2.5		-2.5
2	10	10	0				
3	8	4	-4.0	4.0	-4.0		-4.0
4	17	6	-11.0	10.0	-10.0		-10.0
5	17	23	6.0	7.5	7.5	7.5	
6	12	6	-6.0	7.5	-7.5		-7.5
7	16	11	-5.0	5.0	-5.0		-5.0
8	16	10	-6.0	7.5	-7.5		-7.5
9	26	20	-6.0	7.5	-7.5		-7.5
10	8	5	-3.0	2.5	-2.5		-2.5
11	18	17	-1.0	-1.0	-1.0		-1.0
12	9	9	0				
Total	161	122				7.5	47.5

Table 6.13 Occurrences of mismatches for human selection functions for unskilled operators (n =10).

ii) Set-up functions

The variables involved are mismatches that have occurred in set-up functions.

Subject	Qbef	Qaft	Diff.	Rank	Signed Rank	Sum +ve	Sum -ve
1	2	0	-2	4.5	-4.5		-4.5
2	3	3	0				
3	20	19	-1	2.0	-2.0		-2.0
4	4	2	-2	4.5	-4.5		-4.5
5	7	4	-3	6.5	-6.5		-6.5
6	3	3	0				
7	0	0	0				
8	0	0	0				
9	13	19	6	8.0	8.0	8.0	
10	27	10	-17	11.0	-11.0		-11.0
11	0	0	0				
12	21	10	-11	10.0	-10.0		-10.0
13	15	16	1	2.0	2.0	2.0	
14	17	8	-9	9.0	-9.0		-9.0
15	4	7	3	6.5	6.5	6.5	
16	6	5	-1	2.0	-2.0		-2.0
Total	142	106				16.5	49.5

Table 6.14 Occurrences of mismatches for set-up functions for skilled operators (n=11).

The variables involved are mismatches that have occurred in set-up functions. From Table 6.14, by Wilcoxon matched-pairs signed ranks test, (n=11). Tobt.=16.5 > Tcrit.=11 at alpha=0.05 for a Two-tailed test. The result is not significant and therefore it fails to reject H_0. There is no difference between the occurrence of mismatches in set-up functions before FBS experiments when compared to mismatches after the experiments for skilled operators.

Subject	Qbef.	Qaft.	Diff.	Rank	Signed Rank	Sum +ve	Sum -ve
1	1	1	0				
2	12	14	2	2.0	2.0	2.0	
3	8	5	-3	4.0	-4.0		-4.0
4	13	6	-7	7.5	-7.5		-7.5
5	34	25	-9	9.0	-9.0		-9.0
6	13	11	-2	2.0	-2.0		-2.0
7	20	8	-12	11.0	-11.0		-11.0
8	19	14	-5	6.0	-6.0		-6.0
9	27	17	-10	10.0	-10.0		-10.0
10	9	5	-4	5.0	-5.0		-5.0
11	19	12	-7	7.5	-7.5		-7.5
12	8	6	-2	2.0	-2.0		-2.0
Total	183	124				2	64

Table 6.15 The occurrences of mismatches for set-up functions for unskilled operators (n=11).

From Table 6.15, by Wilcoxon matched-pairs signed ranks Test, (n=11).
Tobt. = 2 < Tcrit. = 11 at alpha = 0.05 for a Two-tailed test. The result is significant and therefore H_o is rejected in favour of H_1. There is a difference between the occurrence of mismatches in set-up functions before the FBS experiments when compared to mismatches after the experiments for unskilled operators.

iii) Inspection functions

The variables involved are mismatches that have occurred in inspection functions.

From Table 6.16, by Wilcoxon matched-pairs signed ranks Test, (n = 10).
Tobt. = 16 > Tcrit. = 8 at alpha = 0.05 for a Two-tailed test. The result is non-significant and therefore it fails to reject H_o. There is no difference between the occurrence of mismatches before FBS experiments compared to that after the experiments in inspection functions for skilled operators in turning operations.

Subject	Qbef	Qaft	Diff.	Rank	Signed Rank	Sum +ve	Sum -ve
1	4	3	-1	2	-2		-2
2	2	0	-2	4	-4		-4
3	10	13	3	6	6	6	
4	4	4	0				
5	5	5	0				
6	0	1	1	2	2	2	
7	0	0	0				
8	0	0	0				
9	4	7	3	6	6	6	
10	22	5	-17	10	-10		-10
11	0	0	0				-8
12	11	7	-4	8	-8		-6
13	11	8	-3	6	-6		-9
14	16	6	-10	9	-9		
15	4	5	1	9	2	2	
16	5	5	0				
Total	98	69				16	39

Table 6.16 Occurrences of mismatches for inspection functions in turning operations for skilled operators (n=10).

From Table 6.17, by Wilcoxon matched-pairs signed ranks Test, (n=11) Tobt. = 6.0 < Tcrit. = 11 at alpha = 0.05 for a Two-tailed test. The result is significant and therefore reject H_o in favour of H_1. There is a difference between the occurrence of mismatches in inspection functions before the FBS experiments when compared to that after the experiments for unskilled operators.

j) Relationships between mismatches and categories of skill for respective human functions using Mann-Whitney U tests.

i) Selection functions

From Table 6.18, before FBS experiments, (for n=11) U'=117, U=75, Uobt.=75>Ucrit.=53, the result is non-significant and it fails to reject H_o. There is no relationship between skill and mismatches for selection functions before FBS experiments.

After FBS experiment, U' = 129.5, U = 62.5, Uobt = 62.5 > Ucrit. = 53, the result is non-significant and it fails to reject H_0. There is no relationship between skill and mismatches for selection functions after FBS experiments.

Subject	QBef	Qaft	Diff.	Rank	Signed Rank	Sum +ve	Sum -ve
1	1	0	-1	-3.0	-3.0		-3.0
2	6	5	-1	-3.0	-3.0		-3.0
3	3	1	-2	-7.0	-7.0		-7.0
4	2	1	-1	-3.0	-3.0		-3.0
5	9	6	-3	-9.0	-9.0		-9.0
6	2	0	-2	-7.0	-7.0		-7.0
7	9	5	-4	-10.0	-10.0		-10.0
8	12	10	-2	-7.0	-7.0		-7.0
9	18	11	-7	-11.0	-11.0		-11.0
10	2	3	1	3.0	3.0	3.0	
11	14	15	1	3.0	3.0	3.0	
12	4	4	0				
Total	82	60				6.0	60.0

Table 6.17 Occurrences of mismatches for inspection functions for unskilled operators (n=11).

ii) Set-up functions

From Table 6.19, by Mann-Whitney U Test, before FBS experiments,U'=136.5, U=63.5, Uobt. = 63.5 >Ucrit.=53. The result is not significant and it fails to reject H_0. There is no relationship between skill and mismatches in set-up functions.

After FBS experiments, U'=115, U=63.5, Uobt.=63.5 >Ucrit.=53. The result is not significant and it fails to reject H_0. There is no relationship between skill and mismatches in set-up functions.

Subject	Qbefore	Rank	Qafter	Rank
1	3	4	0	2.5
2	5	6	4	9.0
3	24	27	19	25.5
4	7	9	4	9.0
5	6	7.5	3	6.5
6	6	7.5	3	6.5
7	0	1.5	0	2.5
8	0	1.5	0	2.5
9	13	15.0	17	23.5
10	23	26.0	6	13.0
11	1	3.0	0	2.5
12	20	24.0	19	25.5
13	17	21.0	13	22.0
14	21	25.0	8	15.0
15	14	16.5	9	15.5
16	14	13.5	9	16.5
Total		211.0		198.5
17	4	5.0	1	5.0
18	10	13.0	10	19.5
19	8	10.0	4	9.0
20	17	21.0	6	13.0
21	17	21.0	23	28.0
22	12	14.0	6	13.0
23	16	18.5	11	21.0
24	16	18.5	10	19.5
25	26	28.0	20	27.0
26	8	11.0	5	11.5
27	18	23.0	17	23.5
28	9	12.0	9	18.5
Total		195.0		207.5

Table 6.18 Occurrences of mismatches for selection functions for skilled (1-16) and unskilled (17-28) operators.

Subject	Qbefore	Rank	Qafter	Rank
1.	2	5.0	0	2.5
2.	3	6.5	3	7.5
3.	20	23.5	19	26.5
4.	4	8.5	2	6.0
5.	7	11.0	4	9.0
6.	3	6.5	3	7.5
7.	0	2.0	0	2.5
8.	0	2.0	0	2.5
9.	13	16.0	19	26.5
10.	27	26.0	10	18.5
11.	0	2.0	0	2.5
12.	21	25.0	10	18.5
13.	15	19.0	16	24.0
14.	17	20.0	8	16.5
15.	4	8.5	7	15.0
16.	6	10.0	5	11.0
Total		191.5		196.5
17.	1	4.0	1	5.5
18	12	15.0	14	22.5
19.	8	12.5	5	11.0
20.	13	17.5	6	13.5
21.	34	28.0	25	28.0
22.	13	17.5	11	20.0
23.	20	23.5	8	16.5
24.	19	21.5	14	22.5
25.	27	27.5	17	25.0
26.	9	14.0	5	11.0
27.	19	21.5	12	21.0
28.	8	12.5	6	13.5
Total		213.0		206.5

Table 6.19 Occurrences of mismatches for set-up functions for skilled and unskilled operators.

iii) Inspection functions

From Table 6.20, by Mann-Whitney U Test, before FBS experiments, U'=105.5, U=86.5, Uobt.=86.5 > Ucrit.=53. The result is non-significant and it fails to reject H_0. There is no relationship between skill and mismatches in inspection functions.

iii) Inspection functions

Subject	Qbefore	Rank	Qafter	Rank
1.	4	13.0	3	10.5
2.	2	7.5	0	3.5
3.	10	21.0	13	27.0
4.	4	13.0	4	12.5
5.	5	16.5	5	16.5
6.	0	2.5	1	8.0
7.	0	2.5	0	3.5
8.	0	2.5	0	3.5
9.	4	13.0	7	27.5
10	22	28.0	5	16.5
11.	0	2.5	0	3.5
12.	11	22.5	7	22.5
13.	11	22.5	8	24.0
14.	16	26.0	6	20.5
15.	4	13.0	5	16.5
16.	5	16.5	5	16.5
Total		R1=222.5		R1=227.5
17.	1	5.0	0	3.5
18.	6	18.0	5	16.5
19.	3	10.0	1	8.0
20.	2	7.5	1	8.0
21.	9	19.5	6	20.5
22.	2	7.5	0	3.5
23.	9	19.5	5	16.5
24.	12	24.0	10	2.5
25.	18	27.0	11	26.0
26.	2	7.5	3	10.5
27.	14	25.0	15	28.0
28.	4	13.0	4	12.5
Total		R2=183.5		R2=178.5

Table 6.20 Occurrences of mismatches for inspection functions for skilled and unskilled operators (n = 28).

After FBS experiments, U' = 100.5 , U = 91.5.Uobt.=91.5 > Ucrit.=53, The result is non-significant and it fails to reject H_0. There is no relationship between skill and mismatches in inspection functions.

6.4.2 Mismatches and Self-confidence

Hypothesis 2 : Operators having high self-confidence commit less mismatches.

The purpose of the analysis was to establish the relationship between self-confidence and mismatches. Since there are two sets of data for self-confidence shown in Figure 6.1 i.e. from questionnaires before FBS experiment (sc1) and from questionnaires after FBS experiments (sc2), it is necessary to establish whether there is any difference between the two values. The Wilcoxon Matched-Pairs Signed Ranks (WMPSR) test was used for this purpose.

a) Test for any difference between self-confidence before and after FBS experiment using the Wilcoxon Technique

The results using WMPSR tests are shown in Table 6.21 and 6.22 for skilled and unskilled operators respectively.

From Table 6.21, by Wilcoxon matched-pairs signed ranks Test (n = 4),
Tobt. = 4 > Tcrit. = 0 at alpha = 0.05 for a One-tailed test. The result is non-significant and therefore it fails to reject H_0. There is no difference between self-confidence before (sc1) and after the FBS experiments (sc2) for skilled operators.

From Table 6.22, by Wilcoxon matched-pairs signed ranks Test, Tobt.=6 >Tcrit.=0 at alpha = 0.05 for a Two-tailed test. The result is non-significant and therefore it fails to reject H_0. There is no difference between self-confidence before and after the FBS experiments for unskilled operators.

Subject	Qbef	Qaft	Diff.	Rank	Signed Rank	Sum +ve	Sum -ve
1.	10	10	0				
2.	7	7	0				
3.	9	9	0				
4.	10	10	0				
5.	10	10	0				
6.	4	4	0				
7.	9	9	0				
8.	5	5	0				
9.	9	8	-1	2	-2		-2
10.	10	9	-1	2	-2		-2
11.	9	9	0				
12.	8	10	2	4	4	4	
13.	8	8	0				
14.	10	10	0				
15.	9	8	-1	2	-2		-2
16.	10	10	0				
Total						4	6

Table 6.21 Self-confidence before and after FBS experiments for skilled operators (n=4).

Subject	Qbef	Qaft	Diff	Rank	Signed Rank	Sum +ve	Sum -ve
1.	7	7	0				
2.	3	3	0				
3.	7	5	-2	3	-3		-3
4.	7	5	-2	3	-3		-3
5.	8	4	-4	6	-6		-6
6.	6	6	0				
7.	6	4	-2	3	-3		-3
8.	4	4	0				
9.	4	6	2	3	3	3	
10.	7	7	0				
11.	6	4	2	3	-3	3	
12.	6	6	0				
Total						6	15

Table 6.22 Self-confidence before and after the FBS experiments for unskilled operators (n=6).

b) Relationships between mismatches from FBS experiments and self-confidence using Spearman Correlation Coefficients.

i) Skilled and unskilled operators

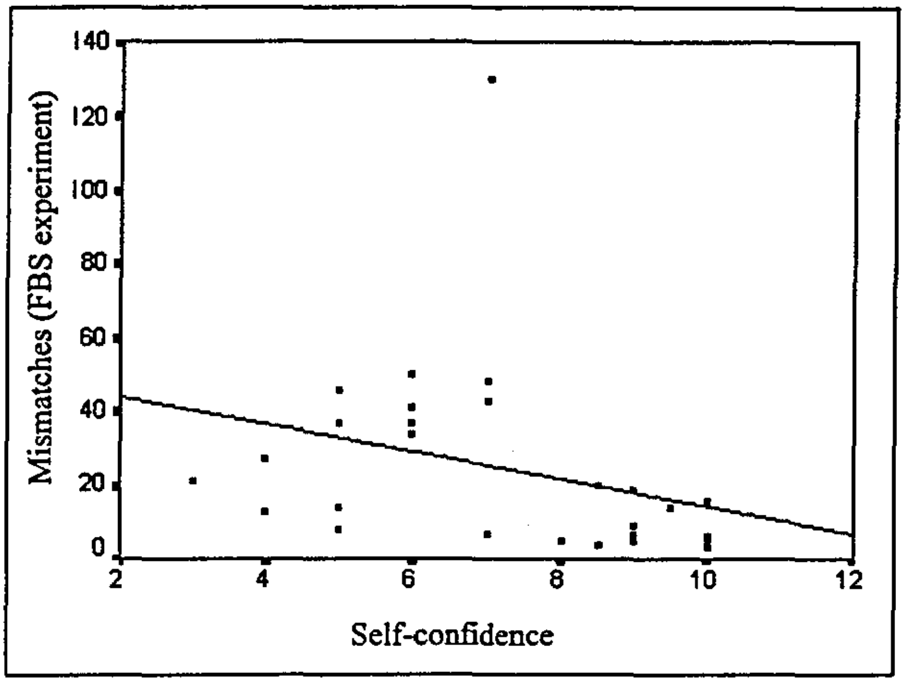


Figure 6.8 Linear regression of mismatches (FBS experiments) against the self-confidence (skilled and unskilled operators)

From Figure 6.8, the result for skilled and unskilled operators indicates that the correlation between mismatches (FBS experiments) and self-confidence (mean values) is Rs = -0.5038, significant at alpha = 0.006 level (two-tailed test). Thus we could reject H_0 at the alpha = 0.006 level concluding that the mismatches and self-confidence are associated. There is evidence that operators having high self-confidence commit less mismatches.

ii) Skilled operators

From Figure 6.9, result for skilled operators indicates that the correlation between mismatches (FBS experiments) and self-confidence (mean values) is Rs = -0.0461, not significant at alpha = 0.865 level (two-tailed test). Thus it fails to reject H_o concluding that the mismatches and self-confidence are not associated for skilled operators.

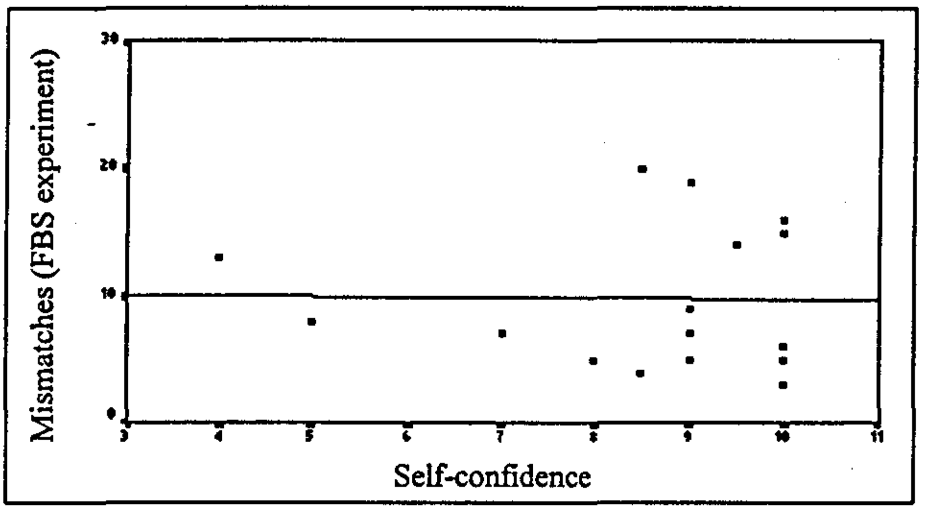


Figure 6.9 Linear regression of mismatches (FBS experiments) against the self-confidence (skilled operators)

6.4.3. Mismatches and Level of Trust

Hypothesis 3 : Operators having a high level of trust commit less mismatches.

a) Differences between level of trust before and after FBS experiment using the Wilcoxon Technique

The results using WMPSR tests are shown in Table 6.23 and 6.24 for skilled and unskilled operators respectively. The variables involved are shown in Figure 6.1 i.e. level of trust before FBS experiment (tr1) and that after FBS experiment (tr2).

Subject	Qbef	Qaft	Diff	Rank	Signed Rank	Sum +ve	Sum -ve
1.	10	10	0				
2.	7	7	0				
3.	9	9	0				
4.	6	10	4	6	6	6	
5.	9	8	-1	2.5	-2.5		-2.5
6.	6	6	0				
7.	9	9	0				
8.	8	8	0				
9.	5	8	3	5	5	5	
10.	8	9	1	2.5	2.5	2.5	
11.	9	10	1	2.5	2.5	2.5	
12.	8	9	1	2.5	2.5	2.5	
13.	6	6	0				
14.	9	9	0				
15.	9	9	0				
16.	10	10	0				
Total						18.5	2.5

Table 6.23 Level of Trust for skilled operators (n=6).

From Table 6.23, by Wilcoxon matched-pairs signed ranks Test, (n = 6) Tobt. = 2.5 > Tcrit. = 0 at alpha = 0.05 for a Two-tailed test. The result is non-significant and it fails to reject H_0. It is concluded that there is no difference between level of trust before and after the FBS experiments for skilled operators.

From Table 6.24, by Wilcoxon matched-pairs signed ranks Test (n=10), Tobt.= 21.5 >Tcrit.=8 at alpha = 0.05 for a Two-tailed test. The result is non-significant and it fails to reject H_0. There is no difference between the level of trust before and after FBS experiments for unskilled operators.

Subject	QBef	Qaft	Diff.	Rank	Signed Rank	Sum +ve	Sum -ve
1.	7	7	0				
2.	7	6	-1	3.0	-3.0		-3.0
3.	5	9	4	10.0	10.0	10.0	
4.	4	6	2	6.5	6.5	6.5	
5.	7	8	1	3.0	3	3.0	
6.	5	8	3	8.0	8	8.0	
7.	9	8	-1	3.0	-3		-3.0
8.	7	6	-1	3.0	-3		-3.0
9.	9	6	-3	9.0	-9		-9.0
10.	9	9	0				
11.	7	8	1	3.0	3.0	3.0	
12.	7	5	-2	6.5	-6.5		-6.5
Total						33.5	21.5

Table 6.24 Level of trust for unskilled operators (n=10).

b) Relationships between mismatches from FBS experiments and level of trust using Spearman Correlation Coefficients

i) Skilled and unskilled operators

From Figure 6.10, result for skilled and unskilled operators indicates that the correlation between mismatches (FBS experiments) and level of trust (mean) is Rs = - 0.4031, significant at alpha = 0.033 level (two-tailed test). Thus we could reject H_0 at the alpha = 0.033 level concluding that the mismatches and level of trust are associated. There is evidence that operators having a high level of trust commit less mismatches.

ii) Skilled operators

From Figure 6.11, result for skilled operators indicates that the correlation between mismatches (FBS experiments) and level of trust (mean) is Rs = -0.3314, significant at alpha = 0.210 level (two-tailed test). Thus it fails to reject H_0 concluding that mismatches and level of trust are not associated for skilled operators.

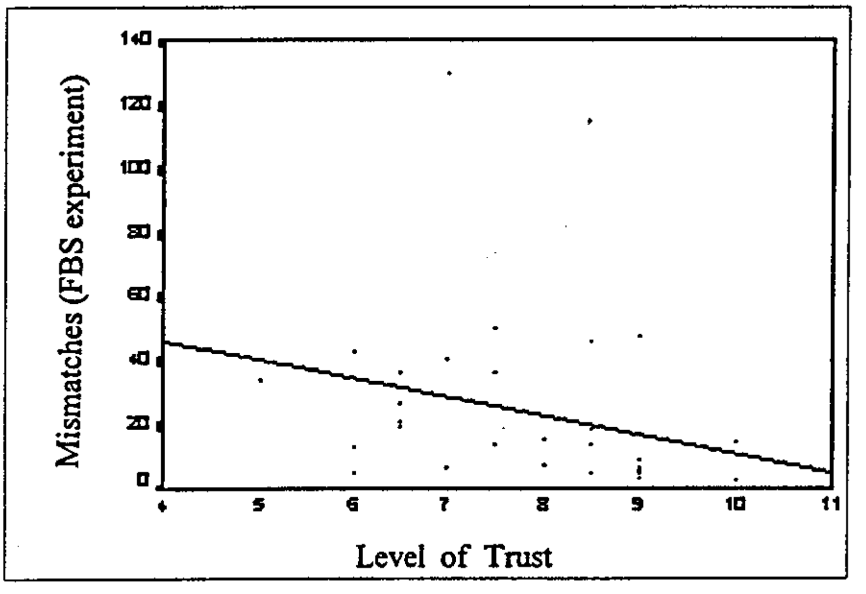


Figure 6.10 Linear regression of mismatches (FBS experiments) against level of trust for skilled and unskilled operators.

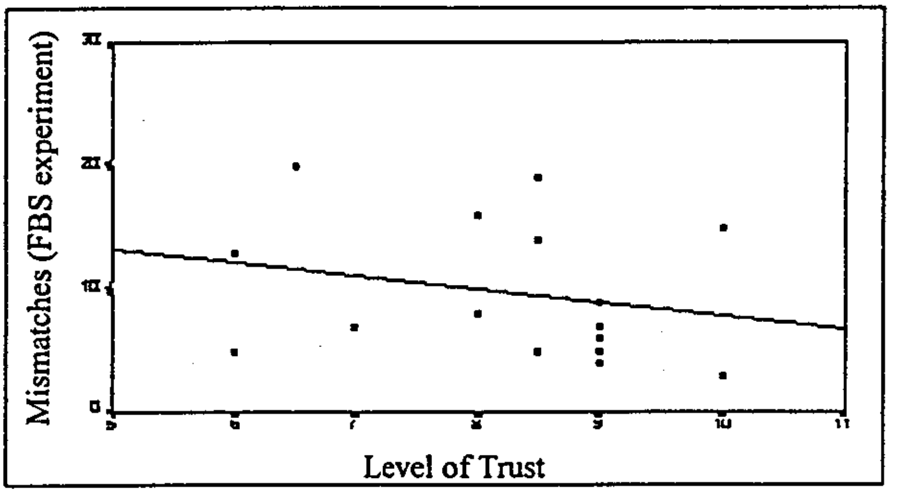


Figure 6.11 Linear regression of mismatches (FBS experiments) against level of trust for skilled operators.

6.4.4. Mismatches and work experience

Hypothesis 4 : The longer the working experience, the fewer mismatches committed.

a) Test for the relationships between mismatches from FBS experiments and work experience using Spearman Correlation Coefficients.

i) For skilled and unskilled operators

In this analysis the variables involved are mismatches from FBS experiment (mme) and work experience (wrk) shown in Figure 6.1. From Figure 6.12 the result indicates that the correlation between mismatches (FBS experiments) and work experience is Rs = -0.6866, significant at alpha = 0.000 level (two-tailed test). Thus we could reject H_0 at the alpha = 0.000 level concluding that mismatches and work experience are associated. There is evidence that operators having longer working experience commit less mismatches.

ii) Skilled operators

From Figure 6.13 the result indicates that the correlation between mismatches (FBS experiments) and work experience is Rs = -0.0062, significant at alpha = 0.982 level (two-tailed test). Thus it fails to reject H_0 concluding that mismatches and work experience are not associated for skilled operators.

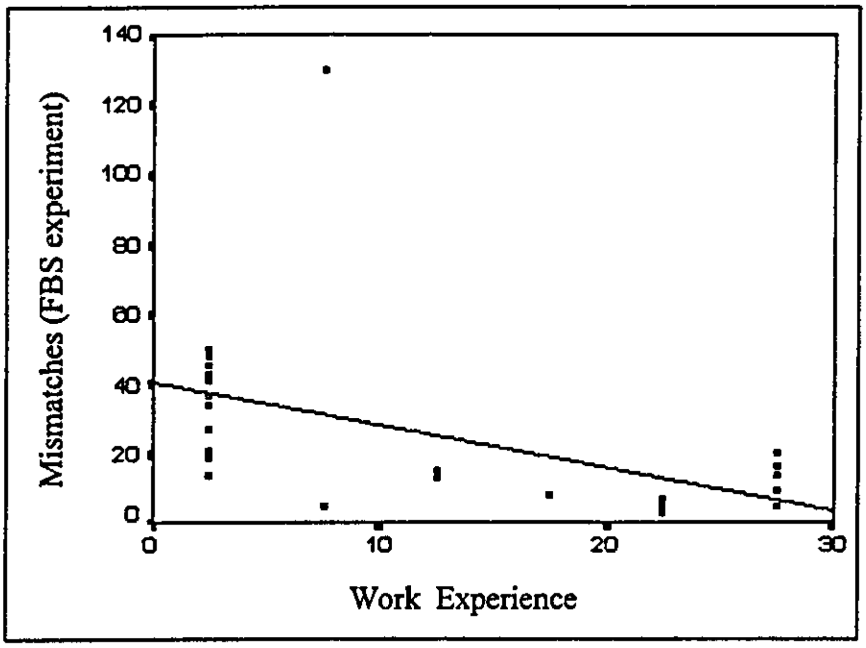


Figure 6.12 Linear regression of mismatches (FBS experiments) against work experience for skilled and unskilled operators.

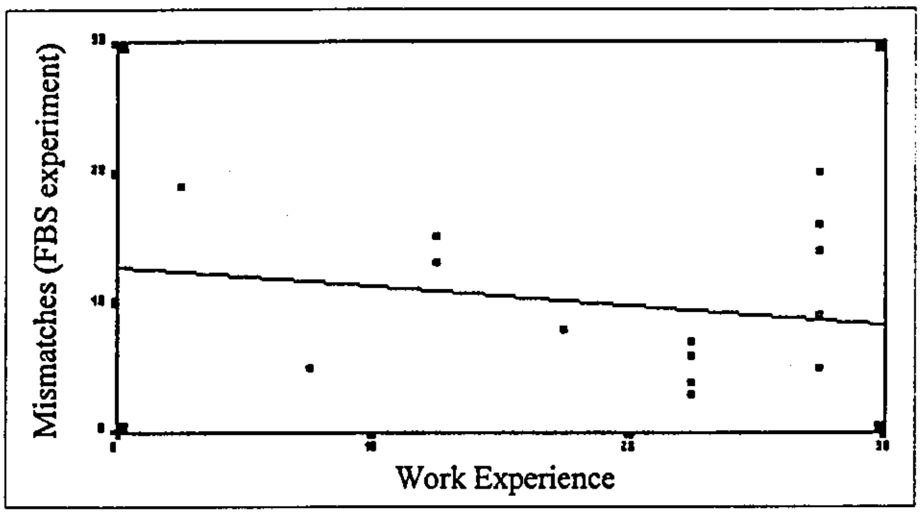


Figure 6.13 Linear regression of mismatches (FBS experiments) against work experience for skilled operators.

6.4.5. Mismatches and age

Hypothesis 5 : The higher the age of operators, the fewer mismatches committed.

a) Relationships between mismatches from FBS experiments and age using Spearman Correlation Coefficients.

i) Skilled and unskilled operators

In this analysis the variables involved are mismatches from FBS experiment (mme) operators' age (age) shown in Figure 6.1. From Figure 6.14 the result indicates that the correlation between mismatches (FBS experiments) and age Rs = -0.5666, significant at alpha = 0.002 level (two-tailed test). Thus we could reject H_o at the alpha = 0.002 level concluding that there is a relationship between mismatches and age. There is evidence that older operators commit less mismatches.

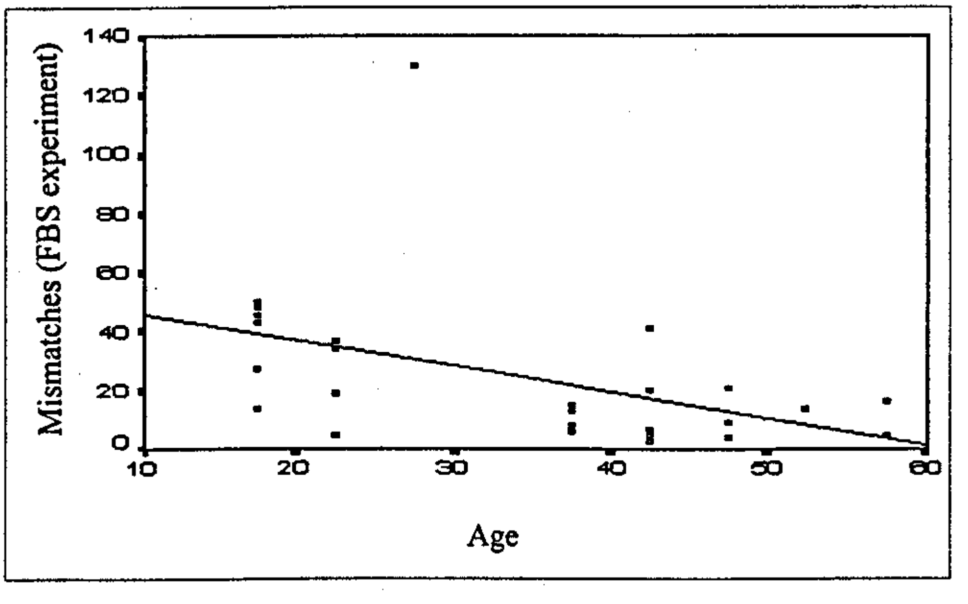


Figure 6.14 Linear regression of mismatches (FBS experiments) against age for skilled and unskilled operators.

Figure 6.15 Linear regression of mismatches (FBS experiments) against age for skilled operators.

From Figure 6.15 the result indicates that the correlation between mismatches (FBS experiments) and age, Rs = -0.0938, significant at alpha = 0.730 level (two-tailed test). Thus it fails to reject H_0 concluding that there is no relationship between mismatches and age for skilled operators.

6.5. Second Objective : Relationships between self-confidence and specific human characteristics.

6.5.1. Self-confidence and skill

Hypothesis 6 : The higher the skill level of operators, the higher their self-confidence.

A study to establish the relationship between self-confidence and skill was aimed at determining whether there is a relationship between self-confidence and skill categories of operators in machining operations. Refering to Figure 6.1, the variables involved are self-confidence (mean values between from sc1 and sc2) and skill categories of operators (sk).

a) Analysis using Mann-Whitney U Rank Test

i) Skilled and unskilled operators

From Table 6.25, R1=98, U1=172, R2=308, U2=20.
It is revealed from Table K that Uobt. = 20 < Ucrit. = 31. The result is significant at a level of alpha = 0.002 for a two-tailed test. H_o is rejected in favour of H_1. It is concluded that there is a relationship between self-confidence and skill.

ii) Skilled operators

From Table 6.26, R1=65.5, U1=25.5, R2=70.5, U2=37.5. It is revealed that Uobt.=25.5>Ucrit.=12. The result is not significant at a level of alpha=0.05 for a Two-tailed test. It fails to reject H_0 and concludes that there is no relationship between self-confidence and skill for skilled operators.

6.5.2. Self-confidence and Level of trust

Hypothesis 7 : The higher the self-confidence, the higher the level of trust.

a) Relationships between self-confidence and level of trust using Spearman correlation coefficients.

In this analysis, the variables involved are the mean values of self-confidence (the mean of sc1 and sc2 shown in Figure 6.1) and the mean values of level of trust (the mean of tr1 and tr2 shown in Figure 6.1).

Subject	Self-confidence	Rank
1.	10.0	26.0
2.	7.0	14.0
3.	9.0	20.5
4.	10.0	26.0
5.	10.0	26.0
6.	4.0	2.5
7.	9.0	20.5
8.	5.0	5.5
9.	8.5	17.5
10.	9.5	23.0
11.	9.0	20.5
12.	9.0	20.5
13.	8.0	16.0
14.	10.0	26.0
15.	8.5	17.5
16.	10.0	26.0
Total		R2=308.0
17.	7.0	14.0
18.	3.0	1.0
19.	6.0	10.0
20.	6.0	10.0
21.	6.0	10.0
22.	6.0	10.0
23.	5.0	5.5
24	4.0	2.5
25.	5.0	5.5
26.	7.0	14.0
27.	5.0	5.5
28.	6.0	10.0
Total		98.0

Table 6. 25 Mean values of self-confidence before and after FBS experiments
Subjects :1-16 skilled. 17-28 unskilled)

Subject	Self-confidence	Rank
1.	10.0	14.0
2.	7.0	3.0
3.	9.0	8.5
4.	10.0	14.0
5.	10.0	14.0
6.	4.0	1.0
7.	9.0	8.5
8.	5.0	2.0
9.	8.5	5.5
Total		R2=70.5
10.	9.5	11.0
11.	9.0	8.5
12.	9.0	8.5
13.	8.0	4.0
14.	10.0	14.0
15.	8.5	5.5
16.	10.0	14.0
Total		R1=65.5

Table 6. 26 Mean values of self-confidence before and after FBS experiments for skilled operators.

i) Skilled and unskilled operators

From Figure 6.16 the results indicate that the correlation between self-confidence and level of trust is Rs = 0.8705, the result is significant at alpha = 0.000 level (two-tailed test). Thus we could reject H_0 at the alpha = 0.000 level concluding that self-confidence and level of trust are associated for skilled and unskilled operators. There is evidence that the higher the self-confidence the higher the level of trust.

ii) Skilled operators

From Figure 6.17 the results indicate that the correlation between self-confidence and level of trust is Rs = 0.6452, the result is significant at alpha = 0.007 level (two-tailed test). Thus we could reject H_0 at the alpha = 0.007 level concluding that self-confidence and level of trust are associated for skilled operators. There is also an evidence that the higher the self-confidence, the higher the level of trust.

Figure 6.16 Linear regression of trust against self-confidence for skilled and unskilled operators.

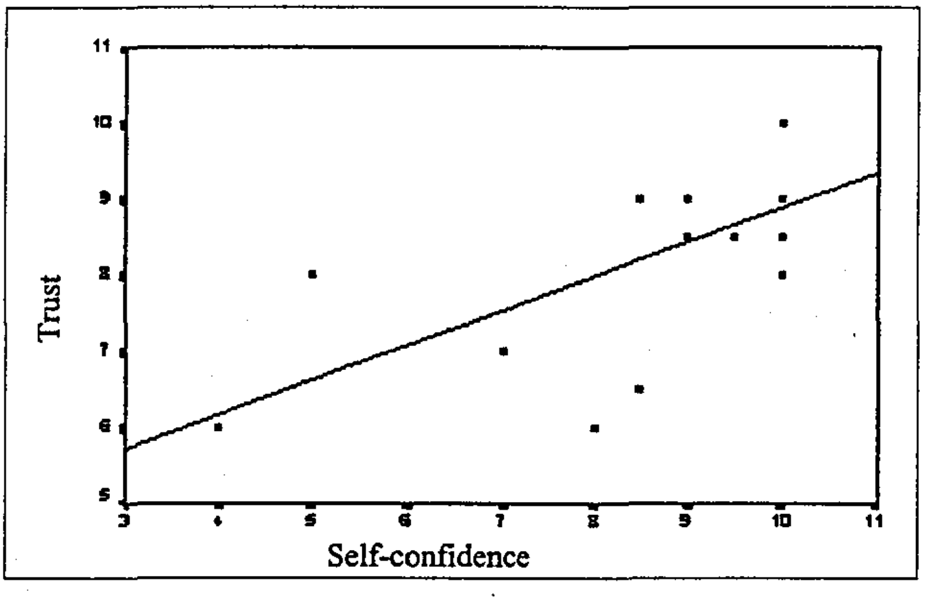


Figure 6.17 Linear regression of trust against self-confidence for skilled operators.

b) Subjective evaluation of operators' self-confidence

Questionnaires	For skilled operators	For unskilled operators
Before FBS experiments	8.7	5.3
After FBS experiments	8.5	5.8

Table 6.27 Mean values of self-confidence obtained from questionnaire responses.

c) Subjective evaluation of operators' level of trust

Questionnaires	For Skilled Operators	For Unskilled Operators
Before FBS Experiments	8.0	6.7
After FBS Experiments	8.0	7.1

Table 6.28 Mean values of trust obtained from questionnaire responses.

The values of self-confidence and trust from questionnaire responses were computed to give the mean values shown in Table 6.27 and 6.28 respectively. Results indicate that skilled operators have higher self-confidence and trust compared to unskilled operators with respect to machining operations. The mean values remain consistent before and after the FBS experiment.

Empirical findings shown in Tables 6.27 and 6.28 reveal that unskilled operators possess low self-confidence and trust in turning operations, and this might due to lack of training, exposure and experience in machining operations. According to Lee and Moray (1994), operators' self-confidence influences their reliance on manual control while trust is more significant for automated systems. In this case manual centre lathes were used in the experiments and these have manual controls and hence handling relies more on operators' self-confidence rather than trust.

It is recognised that the unskilled subjects in this study were novices and may well have had difficulty in judging the performance of both themselves and the machine.

This lower confidence might have caused lower ratings for trust than would have otherwise been the case.

6.5.3. Self-confidence and Working Experience

Hypothesis 8 : The longer the working experience, the higher the self-confidence.

a) Test for the relationships between self-confidence and work experience using Spearman Correlation Coefficients

i) Skilled and unskilled operators

From Figure 6.18 the result indicates that the correlation between self-confidence and work experience is Rs = 0.675, which is significant at alpha = 0.000 level (two-tailed test). Thus we could reject H_o at the alpha = 0.000 level concluding that self-confidence and work experience are associated for skilled and unskilled operators. There is evidence that the higher the working experience the higher the self-confidence.

ii) Skilled operators

From Figure 6.19 the result indicates that the correlation between self-confidence and work experience is Rs = 0.1933, which is significant at alpha = 0.473 level (two-tailed test). Thus it fails to reject H_o concluding that self-confidence and work experience are not associated for skilled operators.

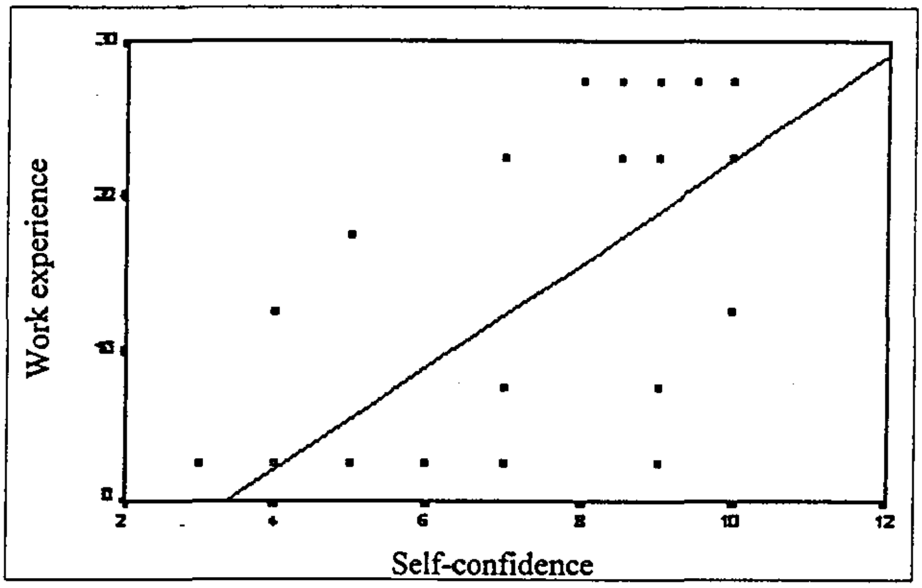


Figure 6.18 Linear regression of work experience against self-confidence for skilled and unskilled operators.

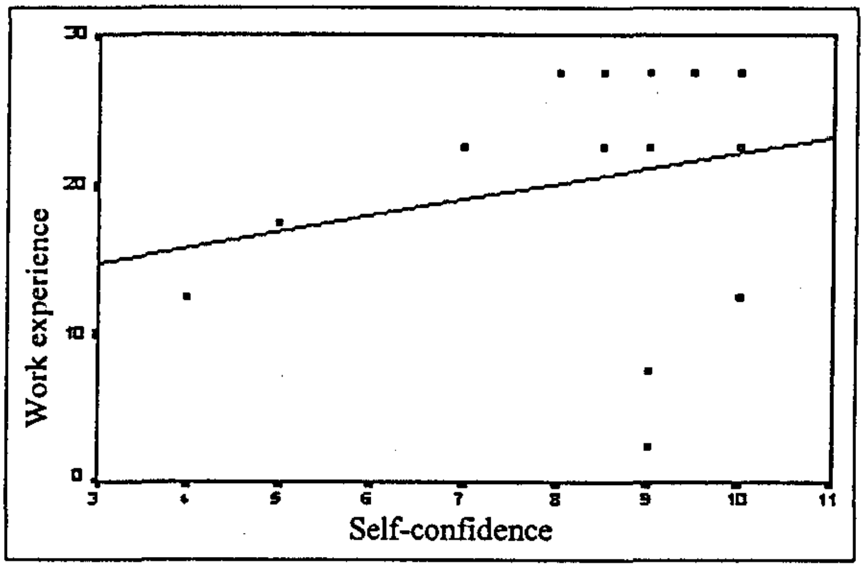


Figure 6.19 Linear regression of work experience against self-confidence for skilled operators.

6.5.4. Self-confidence and Age

Hypothesis 9 : The higher the age of operators, the higher their self-confidence.

a) Test for the relationships between self-confidence and age using Spearman Correlation Coefficients

i) Skilled and unskilled operators

From Figure 6.20 the result indicates that the correlation between self-confidence and the age is Rs = 0.5088, significant at alpha = 0.006 level (two-tailed test). Thus we could reject H_0 at the alpha = 0.006 level concluding that the self-confidence and age are associated for skilled and unskilled operators. There is evidence that the higher the age the higher the self-confidence.

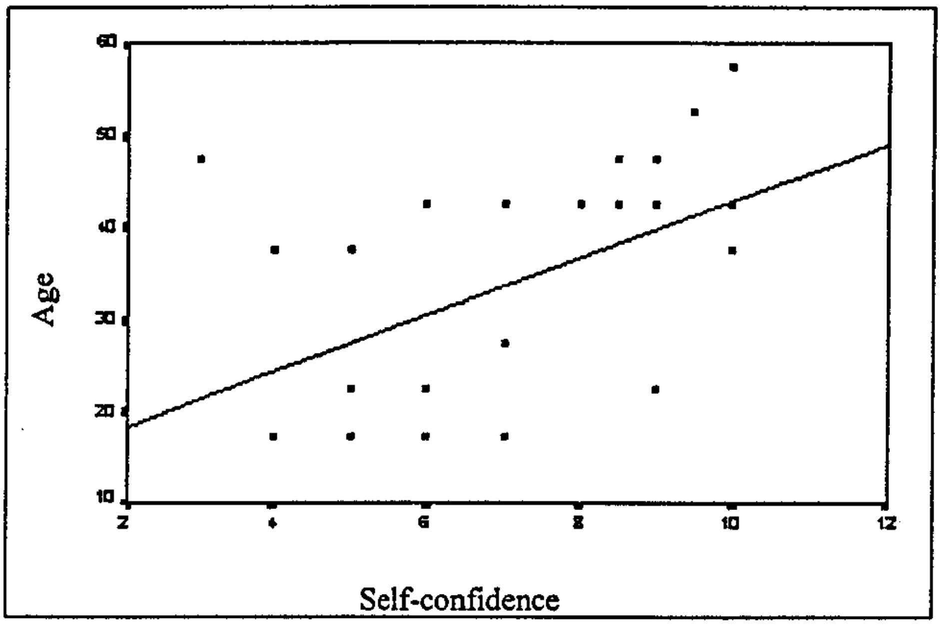


Figure 6.20 Linear regression of age against self-confidence for skilled and unskilled operators.

ii) Skilled operators

From Figure 6.21 the result indicates that the correlation between self-confidence and age is Rs = 0.2685, significant at alpha = 0.315 level (two-tailed test). Thus it fails to reject H_0 concluding that self-confidence and age are not associated for skilled operators.

Figure 6.21 Linear regression of age against self-confidence for skilled operators.

6.6. Third Objective : Relationships between level of trust and human characteristics.

6.6.1. Level of Trust and Skill

Hypothesis 10 : The higher the skill level of operators, the higher the level of trust.

a) Test for relationship between trust and skill categories of operators using Mann-Whitney U Rank Test.

i) Skilled and unskilled operators

From Table 6.29, R1=124.5, U1=145.5, R2=281.5, U2=46.5. Referring to Table K, for n1= 12, n2 = 16,Uobt. = 46.5< Ucrt.=53 for a Two-tailed test at alpha = 0.05. The result is significant where H_0 is rejected in favour of H_1. There is a relationship between skill and trust, and hence the higher the skill of the operators, the higher their level of trust in machining.

ii) Skilled operators

From Table 6.30, R1=69.0, U1=22.0, R2=67.0, U2=41.0.

Referring to Table K, for n1= 7, n2 = 9, Uobt. = 22.0> Ucrt.=12.0 for a Two-tailed test at alpha = 0.05. The result is not significant where it fails to reject H_0. There is no relationship between skill and trust for skilled operators.

6.6.2. Level of trust and working experience

Hypothesis 11 : Operators having longer working experience show higher levels of trust.

a) Analysis using Spearman Rank Correlation

i) Skilled and unskilled operators

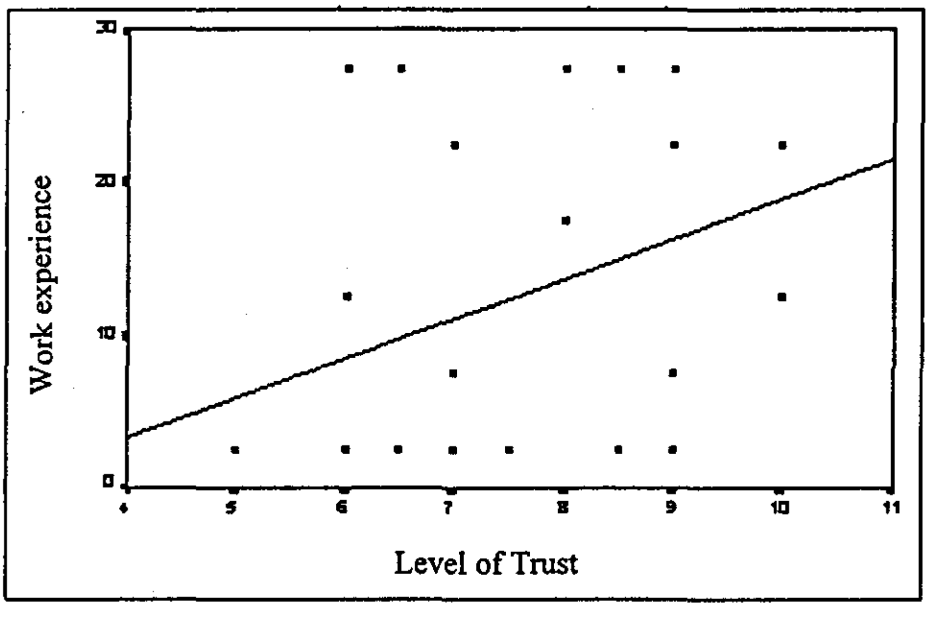


Figure 6.22 Linear regression of work experience against trust for skilled and unskilled operators.

From Figure 6.22 the result indicates that the correlation between work experience and level of trust is Rs = 0.30, significant at alpha = 0.065 level (one-tailed test). Thus it fails to reject H_0 at the alpha = 0.065 level concluding that trust and work experience are not associated for skilled and unskilled operators.

Subject	Level of Trust	Rank
1.	10.0	27.5
2.	7.0	10.0
3.	9.0	23.5
4.	8.0	15.5
5.	8.5	18.5
6.	6.0	3.0
7.	9.0	23.5
8.	8.0	15.5
9.	6.5	6.5
10.	8.5	18.5
11.	9.0	23.5
12.	8.5	18.5
13.	6.0	3.0
14.	9.0	23.5
15.	9.0	23.5
16.	10.0	27.5
Total		R2=281.5
17.	7.0	10.0
18.	6.5	6.5
19.	7.0	10.0
20.	5.0	1.0
21.	7.5	13.0
22.	6.5	6.5
23.	8.5	18.5
24.	6.5	6.5
25.	7.5	13.0
26.	9.0	23.5
27.	7.5	13.0
28.	6.0	3.0
Total		R1=124.5

Table 6.29 Level of trust for skilled (subjects 1-16) and unskilled (subjects 17-28) operators

Subject	Level of Trust	Rank
1.	10.0	15.5
2.	7.0	4.0
3.	9.0	12.0
4.	8.0	5.5
5.	8.5	8.0
6.	6.0	1.5
7.	9.0	12.0
8.	8.0	5.5
9.	6.5	3.0
Total		R2=67.0.
10.	8.5	8.0
11.	9.0	12.0
12.	8.5	8.0
13.	6.0	1.5
14.	9.0	12.0
15.	9.0	12.0
16.	10.0	15.5
Total		R1=69.0

Table 6.30 Level of trust for skilled operators (n=16).

ii) Skilled operators

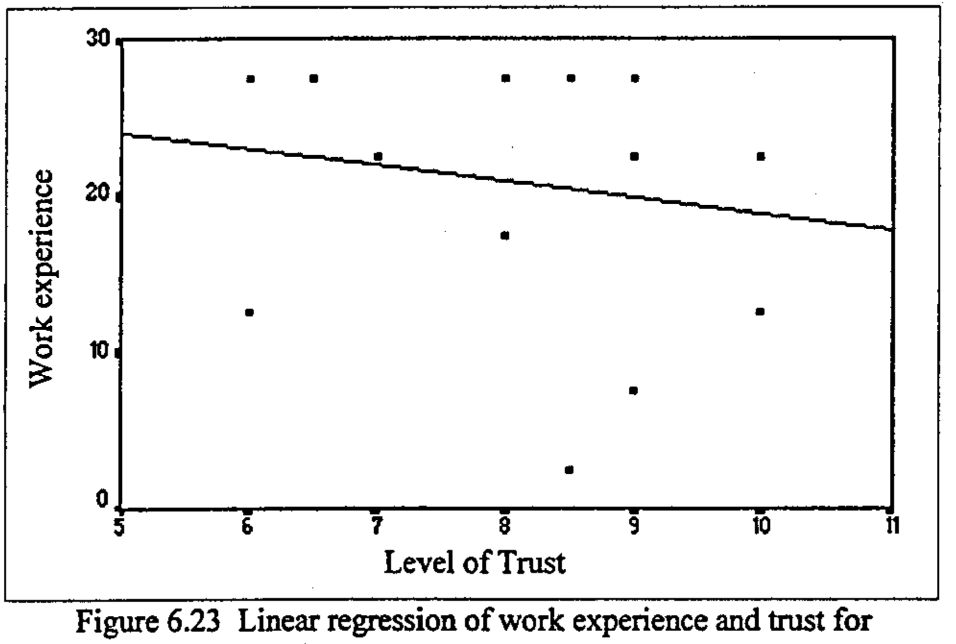


Figure 6.23 Linear regression of work experience and trust for skilled operators.

From Figure 6.23 the result indicates that the correlation between work experience and level of trust is Rs = -0.2507, significant at alpha = 0.349 level (two-tailed test). Thus it fails to reject H_0 concluding that trust and work experience are not associated for skilled operators.

6.6.3. Level of trust and age

Hypothesis 12 : The higher the age of the operators, the higher the level of trust.

a) Analysis using Spearman Rank Correlation

i) Skilled and unskilled operators

From Figure 6.24 the results indicate that the correlation between level of trust (mean values) and age is Rs = 0.19, significant at alpha = 0.163 (one-tailed test). Thus it fails to reject H_0 at the alpha = 0.163 level concluding that the level of trust and age are not associated for skilled and unskilled operators.

ii) Skilled operators

From Figure 6.25 the results indicate that the correlation between level of trust and age is Rs = -0.0785, significant at alpha = 0.773 (two-tailed test). Thus it fails to reject H_0 concluding that the level of trust and age are not associated for skilled operators.

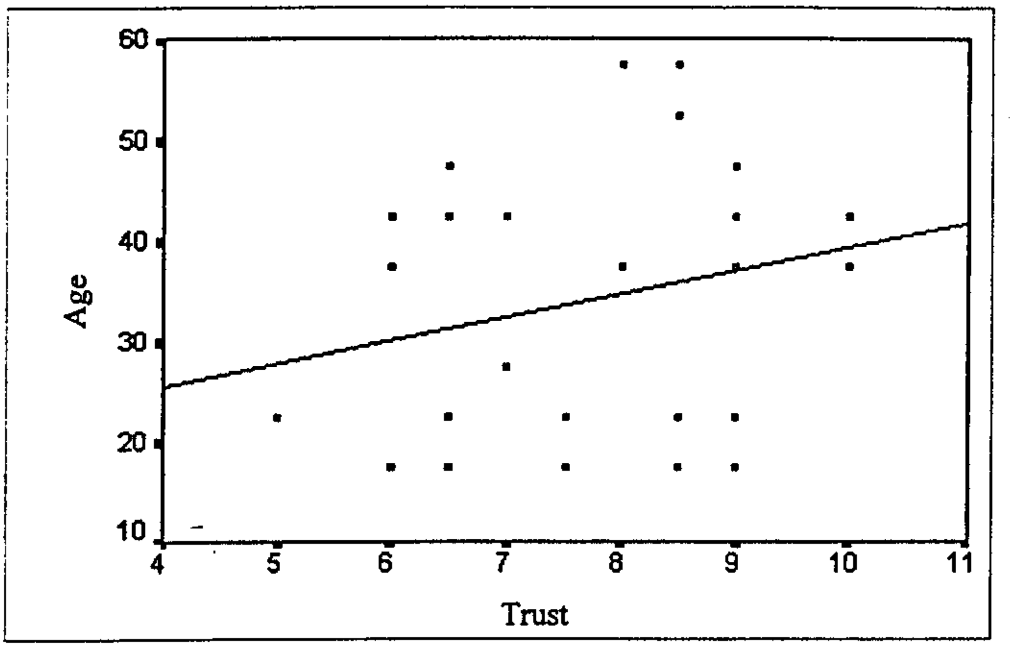


Figure 6.24 Linear regression of age against trust for skilled and unskilled operators.

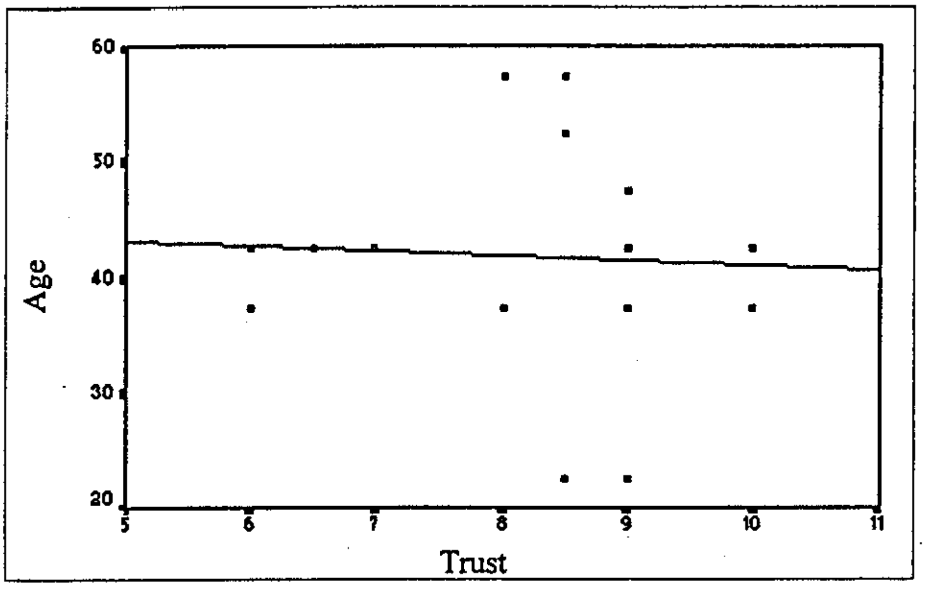


Figure 6.25 Linear regression of age against trust for skilled operators

6.7. Fourth Objective : Relationships between the occurrence of mismatches and preferred levels of automation (PLA).

6.7.1. Mismatches and Preferred Levels of Automation

Hypothesis 13 : Operators who prefer higher levels of automation commit less mismatches.

Relationships are investigated to determine how the pattern of mismatches might vary with preferred levels of automation and this is tested using the above hypothesis. In this analysis the variables involved the preferred levels of automation before FBS experiment (pa1) and after the FBS experiment (pa2) as shown in Figure 6.1.

The preferred level of automation indicated by skilled and unskilled subjects in the questionnaire survey before and after FBS experiment are as shown in Table 6.31 and 6.32 respectively.

a) Differences between preferred level of automation before and after FBS experiments by analysis using Wilcoxon technique.

From Table 6.31, by Wilcoxon matched -pairs signed ranks Test, (n=8), Tobt.=3.5> Tcrit.=2 at alpha = 0.02 for a Two-tailed test. The result is non- significant, hence it fails to reject H_0. Therefore, there is no difference between the preferred levels of automation before and after the FBS experiments for skilled operators.

From Table 6.32, by Wilcoxon matched-pairs signed ranks Test, (n = 8)
Tobt. = 0 = Tcrit. = 0 at alpha = 0.02 for a Two-tailed test and the result is significant, hence it rejects H_0 in favour of H_1. Therefore, there is a difference between the preferred level of automation before and after FBS experiments for unskilled operators.

Subject	QBef	QAft	Diff.	Rank	Signed Rank	Sum +ve	Sum -ve
1.	8	8	0				
2.	9	9	0				
3.	2	2	0				
4.	3	4	1	3.5	3.5	3.5	
5.	10	9	-1	3.5	-3.5		-3.5
6.	8	8	0				
7.	2	9	7	7.5	7.5	7.5	
8.	1	8	7	7.5	7.5	7.5	
9.	6	6	0				
10.	10	10	0				
11.	7	8	1	3.5	3.5	3.5	
12.	5	6	1	3.5	3.5	3.5	
13.	10	10	0				
14.	4	5	1	3.5	3.5	3.5	
15.	5	5	0				
16.	2	3	1	3.5	3.5	3.5	
Total						32.5	3.5

Table 6.31 The preferred level of automation for skilled operators before and after the FBS experiment.

Subject	Qbef	Qaft	Diff	Rank	Signed Rank	Sum +ve	Sum -ve
1.	1	2	1	2.5	2.5	2.5	
2.	8	8	0				
3.	5	6	1	2.5	2.5	2.5	
4.	7	7	0				
5.	4	6	2	5.0	5.0	5.0	
6.	8	9	1	2.5	2.5	2.5	
7.	6	7	1	2.5	2.5	2.5	
8.	5	5	0				
9.	7	7	0				
10.	3	7	4	7.0	7.0	7.0	
11.	5	8	3	6.0	6.0	6.0	
12.	8	8	0				
Total						28.0	0

Table 6.32 The preferred levels of automation for unskilled operators before and after the FBS experiment.

b) Differences between preferred level of automation before and after FBS experiments.

From Table 6.33, by Wilcoxon matched -pairs signed ranks Test, (n=15), Tobt.=5.5< Tcrit.=25 at alpha = 0.05 for a Two-tailed test. H_0 is rejected in favour of H_1. It is concluded that there is a difference between preferred levels of automation before and after FBS experiments for skilled and unskilled operators.

c) Relationship between mismatches (FBS experiments) and the preferred level of automation.

i) Skilled and unskilled operators.

From Table 6.34, it is revealed from Table A that z > 3.458 has a One-tailed probability under H_0 of $p < 0.0003$. Since this p is smaller than alpha = 0.01, H_0 is rejected in favour of H_1. It is concluded that there is a relationship between preferred levels of automation and mismatches in machining for skilled and unskilled operators. Hence, there is evidence that operators who prefer higher levels of automation commit less mismatches.

ii) Skilled operators

From Table 6.35, R1=289.5, U1=102.5, R2=238.5, U2=153.5. Referring to Table K, Uobt.=102.5 > Ucrit. =75.0 for a Two-tailed test at alpha = 0.05. The result is non-significant where it fails to reject H_0. It is concluded that there is no relationship between preferred levels of automation and mismatches in machining for skilled operators.

Subject	QBef	QAft	Diff.	Rank	Signed Rank	Sum +ve	Sum -ve
1.	8	8	0				
2.	9	9	0				
3.	2	2	0				
4.	3	4	1	5.5	5.5	5.5	
5.	10	9	-1	5.5	-5.5		-5.5
6.	8	8	0				
7.	2	9	7	15.0	15.0	15.0	
8.	1	8	6	14.0	14.0	14.0	
9.	6	6	0				
10.	10	10	0				
11.	7	8	1	5.5	5.5	5.5	
12.	5	6	1	5.5	5.5	5.5	
13.	10	10	0				
14.	4	5	1	5.5	5.5	5.5	
15.	5	5	0				
16.	2	3	1	5.5	5.5	5.5	
17.	1	2	1	5.5	5.5	5.5	
18.	8	8	0				
19.	5	6	1	5.5	5.5	5.5	
20.	7	7	0				
21.	4	6	2	11.0	11.0	11.0	
22.	8	9	1	5.5	5.5	5.5	
23.	6	7	1	5.5	5.5	5.5	
24.	5	5	0				
25.	7	7	0				
26.	3	7	4	13.0	13.0	13.0	
27.	5	8	3	12.0	12.0	12.0	
28.	8	8	0				
Total						114.5	5.5

Table 6.33 The Preferred Level of Automation indicated by skilled and unskilled operators before and after the FBS experiment.

Subject	Mismatches	Rank	Preferred Level of Automation	Rank
1.	15	42.0	8	27.5
2.	7	20.5	9	34.0
3.	7	20.5	2	1.5
4.	16	4.3	4	5.5
5.	5	9.5	9	34.0
6.	13	39.0	8	27.5
7.	9	34.0	9	34.0
8.	8	27.5	8	27.5
9.	20	45.0	6	15.0
10.	14	40.5	10	37.5
11.	5	9.5	8	27.5
12.	19	44.0	6	15.0
13.	5	9.5	10	37.5
14.	6	15.0	5	9.5
15.	4	5.5	5	9.5
16.	3	5.5	3	4.5
17.	130	56.0	2	1.5
18.	21	46.0	8	27.5
19.	41	51.0	6	15.0
20.	34	48.0	7	20.5
21.	50	55.0	6	15.0
22.	37	49.5	9	34.0
23.	46	53.0	7	20.5
24.	27	47.0	5	9.5
25.	37	49.5	7	20.5
26.	48	54.0	7	20.5
27.	14	40.5	8	27.5
28.	43	52.0	8	27.5
		R1=1010.0 U1=180.0		R2=587.0 U2=603.0

Table 6.34 Mismatches (from FBS experiments) and Preferred Levels of Automation (obtained from questionaire survey) by skilled and unskilled operators.

Subject	Mismatches	Rank	Preferred Level of Automation	Rank
1.	15	29.0	8	18.0
2.	7	14.5	9	22.5
3.	7	14.5	2	1.0
4.	16	30.0	4	4.5
5.	5	8.0	9	22.5
6.	13	27.0	8	18.0
7.	9	22.5	9	22.5
8.	8	18.0	8	18.0
9.	20	32.0	6	12.0
10.	14	28.0	10	25.5
11.	5	8.0	8	18.0
12.	19	31.0	6	12.0
13.	5	8.0	10	25.5
14.	6	12.0	5	8.0
15.	4	4.5	5	8.0
16.	3	2.5	3	2.5
Total		289.5		238.5

Table 6.35 Mismatches (from FBS experiments) and Preferred Levels of Automation (obtained from questionaire survey) for skilled operators.

6.8. Fifth Objective : Relationships between preferred levels of automation (PLA) and human characteristics.

Levels of automation were studied to determine an approximate level of automation preferred by operators. This is essential considering that the broad spectrum of levels of automation is rather unspecific either for machine design or training procedures. A knowledge of preferred levels of automation is considered to be an important component of automation procedures.

6.8.1. Preferred Levels of Automation and skill

Hypothesis 14 : Skilled operators prefer lower levels of automation.

A study to establish the relationships between preferred levels of automation and skill was undertaken to determine the levels of automation preferred by the different skill categories of operators in machining operations particularly on manual centre lathes.

a) Relationships between preferred levels of automation and skill using Mann-Whitney U Rank Tests.

i) Skilled and unskilled operators

n1=16, R1=244, U'= 84,
n2=9, R2=162, U = 108,

From Table 6.36, by Mann-Whitney U Test, Uobt.=84>Ucrit.=53. The result is not significant and it fails to reject H_0 at alpha = 0.05 significant level. It is concluded that preferred levels of automation and skill in machining are not associated for skilled and unskilled operators.

ii) Skilled operators

n1=7, R1=57, U'= 43,
n2=9, R2=78, U = 22,

From Table 6.37, by Mann-Whitney U Test, Uobt.=22>Ucrit.=12. The result is not significant and it fails to reject H_0 at alpha = 0.05 significant level. It is concluded that preferred levels of automation and skill in machining are not associated for skilled operators.

Subject	Preferred Level of Automation	Rank
1.	8	19.0
2.	9	24.5
3.	2	1.5
4.	4	4.0
5.	9	24.5
6.	8	19.0
7.	9	24.5
8.	8	19.0
9.	6	9.5
10.	10	27.5
11.	8	19.0
12.	6	9.5
13.	10	27.5
14.	5	6.0
15.	5	6.0
16.	3	3.0
Total		R2=244.0
17.	2	1.5
18.	8	19.0
19.	6	9.5
20.	7	13.5
21.	6	9.5
22.	9	24.5
23.	7	13.5
24.	5	6.0
25.	7	13.5
26.	7	13.5
27.	8	19.0
28.	8	19.0
Total		R1=162.0

Table 6.36 The preferred level of automation from the questionnaire survey after the FBS experiment. (Skilled operators : 1-16, Unskilled operators : 17-28)

Subject	Preferred Level of Automation	Rank
1.	8	19.0
2.	9	24.5
3.	2	1.5
4.	4	4.0
5.	9	24.5
6.	8	19.0
7.	9	24.5
8.	8	19.0
9.	6	9.5
Total		R2=78.0
10.	10	27.5
11.	8	19.0
12.	6	9.5
13.	10	27.5
14.	5	6.0
15.	5	6.0
16.	3	3.0
Total		R1=57.0

Table 6.37 The preferred level of automation from the questionnaire survey after the FBS experiment for skilled operators.

6.8.2. Preferred level of automation and Self-confidence

Hypothesis 15 : Operators having high self-confidence prefer lower levels of automation.

a) Correlation between preferred levels of automation and self-confidence using Spearman Correlation Coefficients.

i) Skilled and unskilled operators

From Figure 6.26, the results indicate that the correlation between the preferred level of automation and self-confidence is Rs = -0.1147, and the result is not significant at alpha=0.561 (a Two-tailed test). Thus we fail to reject H_0 at the alpha = 0.561 level concluding that the preferred level of automation and self-confidence are not associated for skilled and unskilled operators.

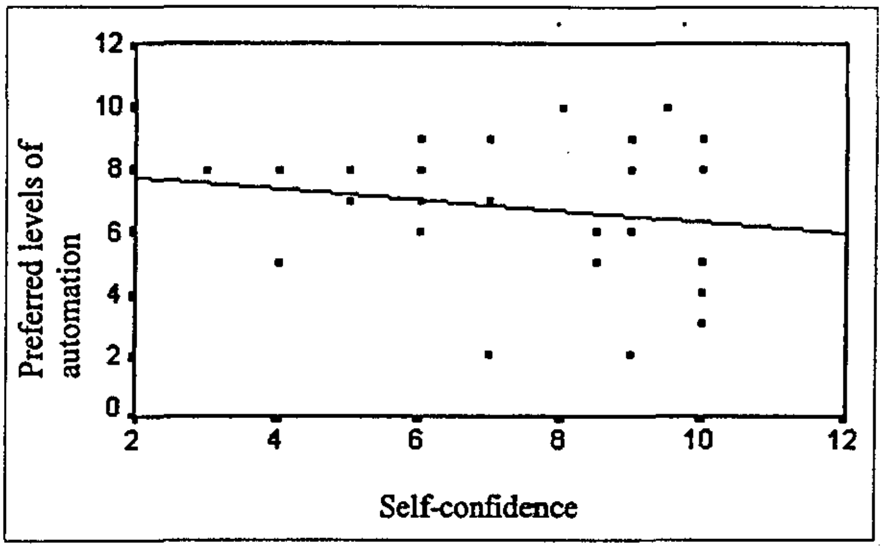


Figure 6.26 A linear regression of the preferred levels of automation against self-confidence for skilled and unskilled operators.

ii) Skilled operators

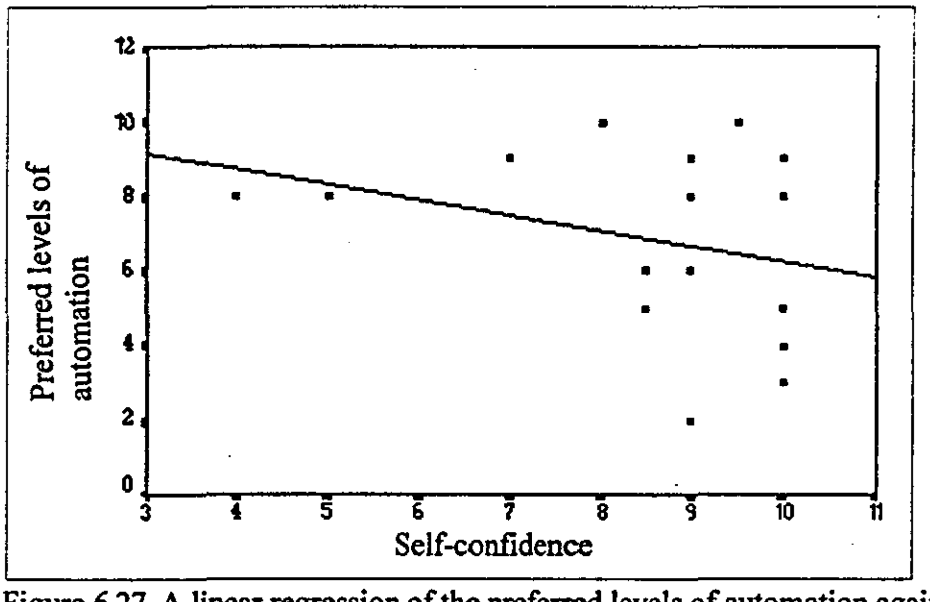


Figure 6.27 A linear regression of the preferred levels of automation against self-confidence for skilled operators.

From Figure 6.27, the results indicate that the correlation between the preferred level of automation and self-confidence is Rs = -0.2820, and the result is not significant at alpha=0.291 (a Two-tailed test). Thus we fail to reject H_0 concluding that the preferred level of automation and self-confidence are not associated for skilled operators.

6.8.3. Preferred Levels of Automation and Level of Trust

Hypotheses 16 : Operators having a higher level of trust prefer a lower level of automation.

a) Correlation between preferred levels of automation and level of trust using Spearman Correlation Coefficients.

i) Skilled and unskilled operators

From Figure 6.28 the results indicate that the correlation between the preferred level of automation and trust is Rs = -0.2165, at alpha = 0.269 (a Two-tailed test). Thus we fail to reject H_0 at the alpha = 0.269 level concluding that the preferred levels of automation and level of trust are not associated for skilled and unskilled operators.

ii) Skilled operators

From Figure 6.29, the results indicate that the correlation between the preferred level of automation and trust is Rs = -0.3951, at alpha = 0.130 (a Two-tailed test). Thus we fail to reject H_0 concluding that the preferred levels of automation and level of trust are not associated for skilled operators.

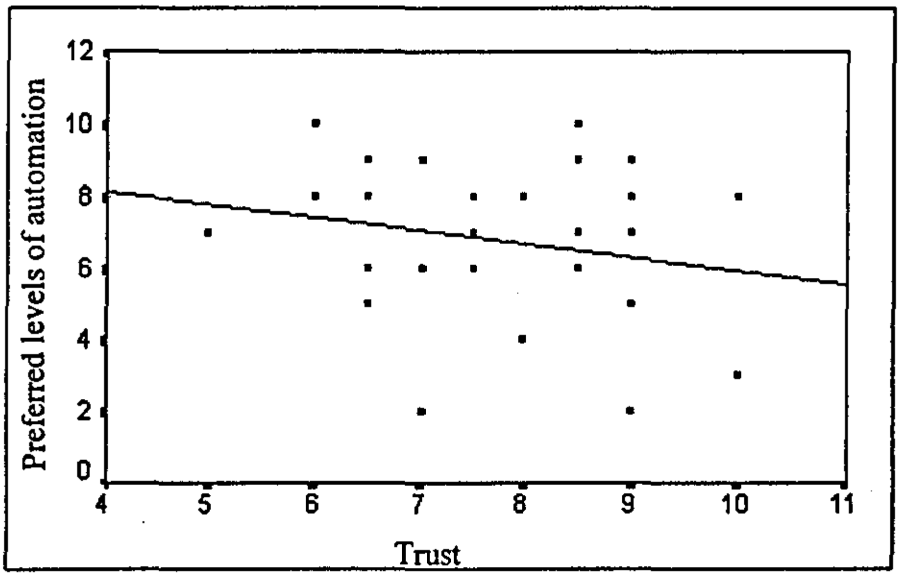


Figure 6.28 A linear regression of the preferred levels of automation against trust for skilled and unskilled operators.

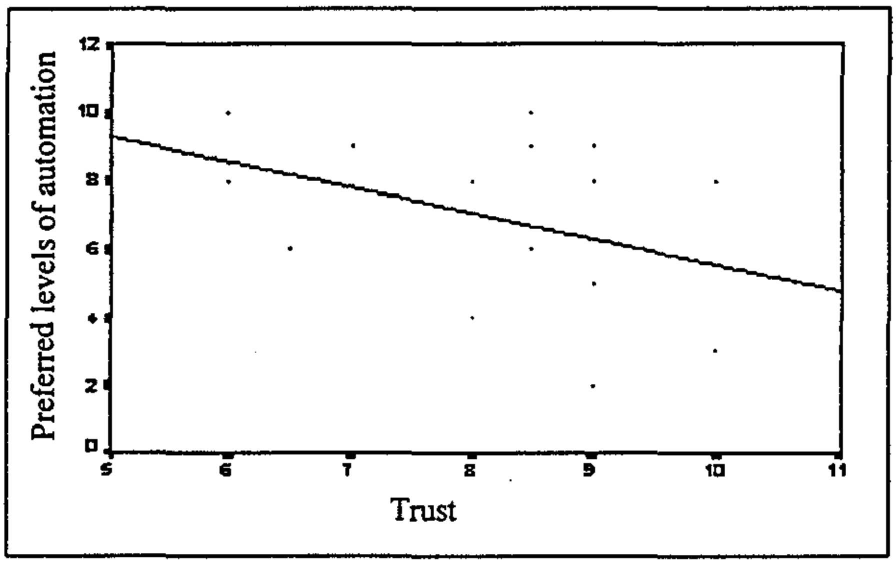


Figure 6.29 A linear regression of the preferred levels of automation against trust for skilled operators.

6.8.4. Preferred Levels of Automation and Work Experience

Hypothesis 17 : Operators having longer working experience prefer lower levels of automation.

The purpose of the analysis was to establish how working experience might relate to preferred levels of automation. Selecting preferences from choices is also the growth of experience. In the absence of material on the relationships between preferences in manufacturing, a study in this direction is justifiable.

a) Correlation between preferred levels of automation and working experience using Spearman Correlation Coefficients.

i) Skilled and unskilled operators

From Figure 6.30 the results indicate that the correlation between the preferred level of automation and working experience is Rs = 0.1299, at alpha = 0.510 (a Two-tailed test). Thus we fail to reject H_0 at the alpha = 0.510 level concluding that the preferred level of automation and working experience are not associated for skilled operators and unskilled operators.

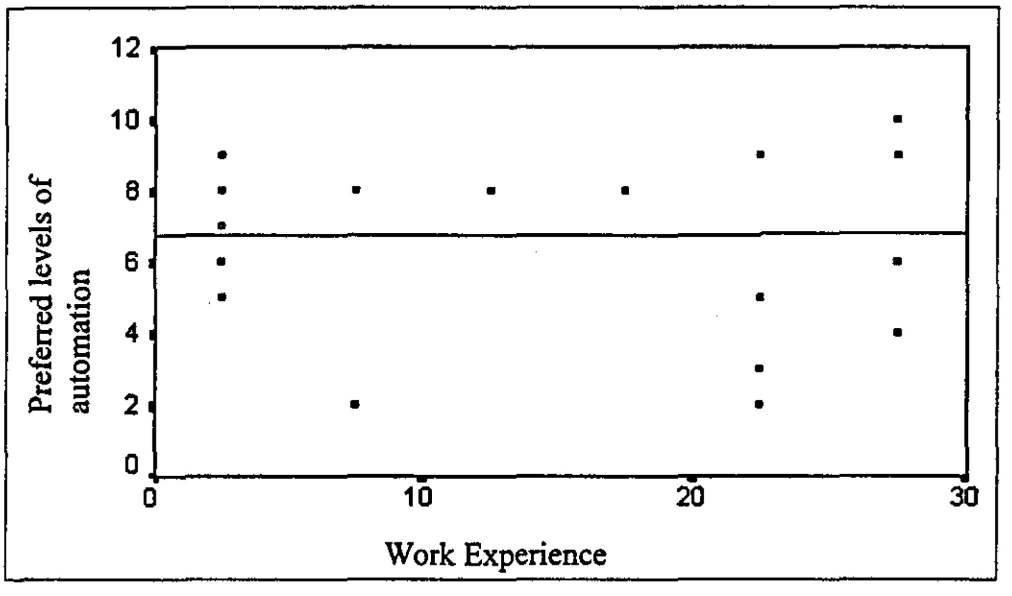


Figure 6.30 A linear regression of the preferred levels of automation against work experience for skilled and unskilled operators.

ii) Skilled operators

From Figure 6.31 the results indicate that the correlation between the preferred level of automation and working experience is Rs = 0.2526, at alpha = 0.345 (a Two-tailed test). Thus we fail to reject H_0 concluding that the preferred level of automation and working experience are not associated for skilled operators.

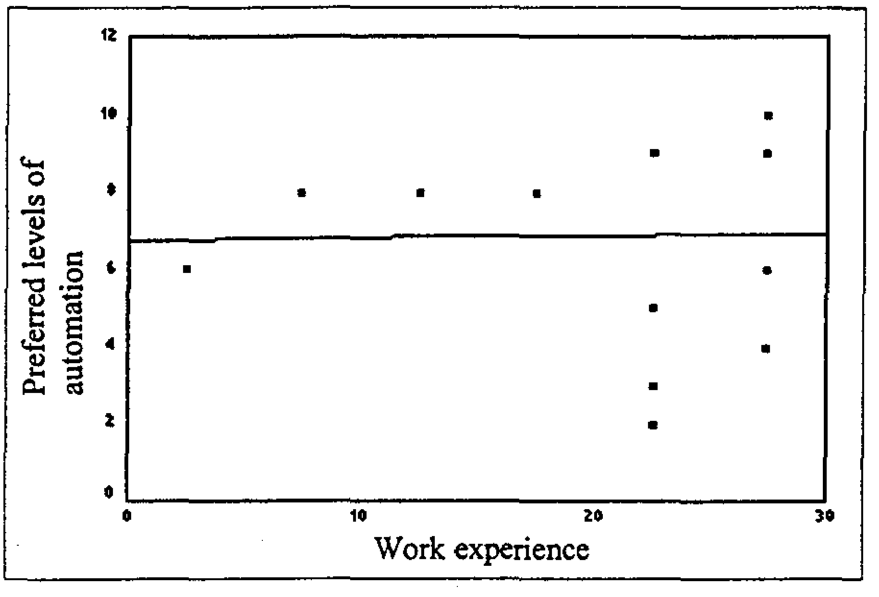


Figure 6.31 A linear regression of the preferred levels of automation against work experience from linear regression for skilled operators

6.8.5. Preferred Levels of Automation and age

Hypothesis 18 : Older operators prefer lower levels of automation.

a) Correlation between preferred levels of automation and age using Spearman Correlation Coefficients.

i) Skilled and unskilled operators

From Figure 6.32 the results indicate that the correlation between the preferred level of automation and age is Rs = 0.1155, significant at alpha = 0.559 (a Two-tailed test). Thus, it fails to reject H_0 at the alpha = 0.559 level concluding that the preferred levels of automation and age are not associated for skilled and unskilled operators.

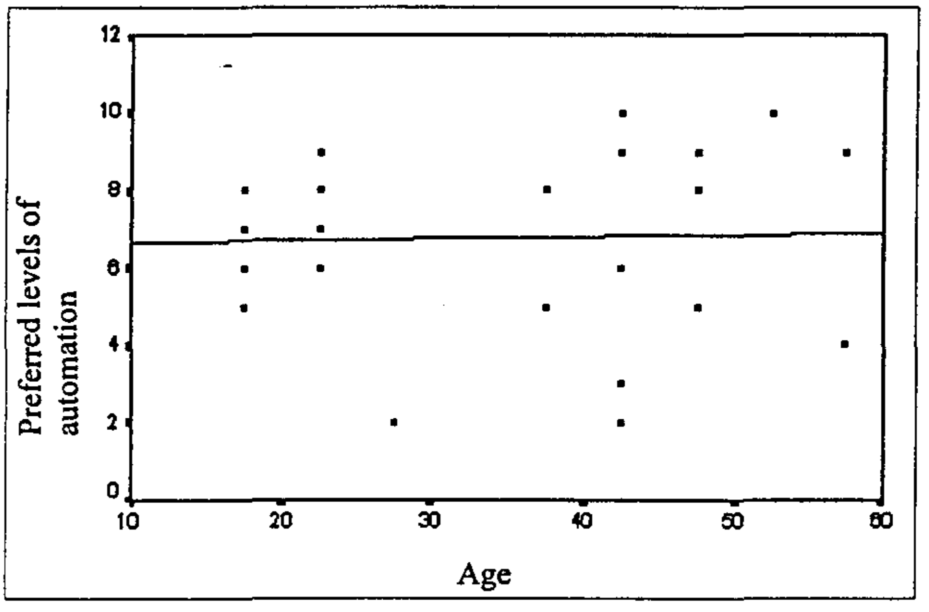


Figure 6.32 A linear regression of the preferred levels automation against age for skilled and unskilled operators.

ii) Skilled operators

From Figure 6.33 the results indicate that the correlation between the preferred level of automation and age is Rs = 0.1290, significant at alpha = 0.634 (a Two-tailed test). Thus, it fails to reject H_0 concluding that the preferred levels of automation and age are not associated for skilled operators.

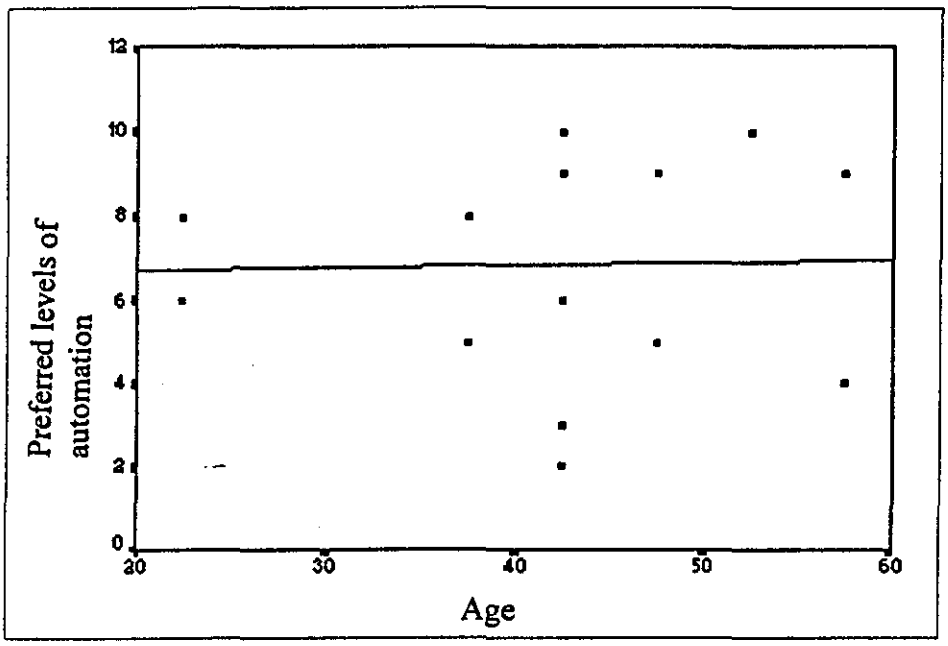


Figure 6.33 A linear regression of the preferred levels automation against age for skilled operators.

6.9. Summary of the findings for the Objectives 1, 2, 3, 4 and 5

The findings obtained by hypotheses testing are summarised in the flow chart shown in Figure 6.34.

6.10. Sixth Objective : To establish the preferred levels of automation

The preferred levels of automation were established subjectively for each human function (i.e. selection, set-up and inspection) and for the overall function.

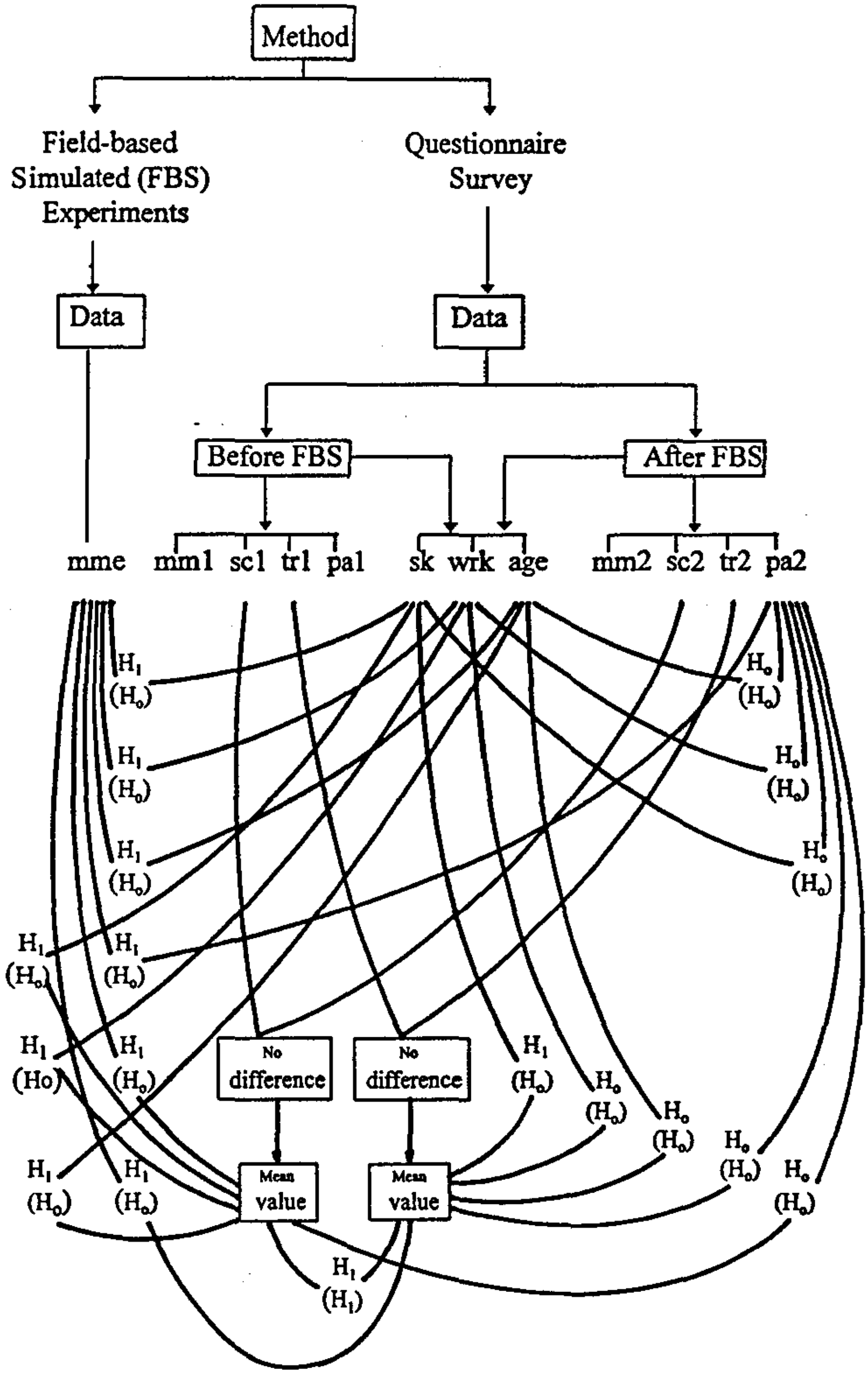


Figure 6.34 Flow chart summarising the relationships between the variables for objective 1-5 for skilled and unskilled operators (in brackets for skilled operators).

6.10.1. The preferred levels of automation

The preferred levels of automation (PLA) were indicated by subjects as responses to the questionnaires. Choices offered in the questionnaires ranged between 1 and 10 i.e. 1 (fully manual) to 10 (fully automatic). Although the levels might appear arbitrary, the primary purpose was to establish if there was any preference among operators for the levels of automation in machining. Based on the results of the questionnaires, it was discovered that subjects have preferences for the levels of automation shown in Table 6.38. The preferred levels were shown to be between 5.0 to 7.0 for both the skilled and unskilled operators.

Questionnaires	Skilled Operators	Unskilled Operators
Before FBS experiment	5.7	5.7
After FBS experiment	6.9	6.3

Table 6.38 Preferred Levels of Automation for both skilled and unskilled operators.

6.10.2. The preferred levels of automation for typical human functions.

In the questionnaires, tasks in machining were given at random to subjects who indicated the preferred levels of automation. Subsequently, the tasks were grouped into the human functions of selection, set-up and inspection as shown in Appendix G. The subjects' preferences for levels of automation are shown in Tables 6.39, 6.40, 6.41, 6.42, 6.43 and 6.44. The average and overall preferred levels of automation are shown in Tables 6.45 and 6.46.

a) Differences between the Preferred Levels of Automation in selection functions before and after the FBS experiments for skilled operators.

From Table 6.39, by Wilcoxon matched-pairs signed ranks Test, $T_{obt.} = 26 > T_{crit.} = 14$ at $\alpha = 0.05$ for a Two-tailed test. The result is non-significant and it fails to reject H_0. It is concluded that there is no difference between preferred levels of automation for selection functions before and after the FBS experiments for skilled operators.

Subject	Qbef	Qaft	Diff.	Rank	Signed Rank	Sum +ve	Sum -ve
1	3.2	2.7	-0.5	6.0	-6.0		-6.0
2	10.0	10.0	0				
3	1.1	1.1	0				
4	2.0	1.0	-1.0	8.0	-8.0		-8.0
5	1.1	1.0	-1.1	10.0	-10.0		-10.0
6	2.0	5.1	-1.0	8.5	-9.0		-9.0
7	2.1	8.4	-0.1	2.0	-2.0		-2.0
8	6.1	1.0	0				
9	8.5	6.0	0.6	7.0	7.0	7.0	
10	1.0	1.0	0				
11	5.4	5.4	0.1	2.0	2.0	2.0	
12	9.2	9.5	0.3	4.0	4.0	4.0	
13	7.4	7.0	-0.4	5.0	-5.0		-5.0
14	6.7	6.8	0.1	2.0	2.0	2.0	
15	2.3	3.5	1.2	11.0	11.0	11.0	
16	4.7	3.4	-1.3	12.0	-12.0		-12.0
Total						26.0	52.0

Table 6.39 Preferred Levels of Automation for the Selection Function for skilled operators.

b) Differences between the Preferred Levels of Automation in selection functions before and after the FBS experiments for skilled and unskilled operators.

From Table 6.40, by Wilcoxon matched-pairs signed ranks Test, Tobt. = 120.5 > Tcrit. = 81 at alpha = 0.05 for a Two-tailed test. The result is non-significant and it fails to reject H_0. It is concluded that there is no difference between preferred levels of automation for selection functions before and after the FBS experiments.

Subject	QBef	QAft	Diff.	Rank	Signed Rank	Sum +ve	Sum - ve
1.	3.2	2.7	-0.5	6.0	-6.0		-0.6
2.	10.0	10.0	0				
3.	1.1	1.1	0				
4.	2.0	1.0	-1.0	11.5	-11.5		-11.5
5.	1.1	1.0	-1.1	14.5	-14.5		-14.5
6.	2.0	5.1	-1.0	11.5	-11.5		-11.5
7.	2.1	8.4	-0.1	2.0	-2.0		-2.0
8.	6.1	1.0	0				
9.	8.5	6.0	0.6	7.0	7.0	7.0	
10.	1.0	1.0	0				
11.	5.4	5.4	0.1	2.0	2.0	2.0	
12.	9.2	9.5	0.3	4.0	4.0	4.0	
13.	7.4	7.0	-0.4	5.0	-5.0		-5.0
14.	6.7	6.8	0.1	2.0	2.0	2.0	
15.	2.3	3.5	1.2	17.5	17.5	17.5	
16.	4.7	3.4	-1.3	19.5	-19.5		-19.5
17.	5.1	4.3	-0.8	8.0	-8.0		-8.0
18.	5.4	6.3	0.9	9.5	9.5	9.5	
19.	5.9	4.0	-1.9	22.5	-22.5		-22.5
20.	7.0	5.7	-1.3	19.5	-19.5		-19.5
21.	6.4	5.3	-1.1	14.5	-14.5		-14.5
22.	7.2	6.1	-1.1	14.5	-14.5		-14.5
23.	7.4	5.7	-1.7	21.0	-21.0		-21.0
24.	5.7	4.8	-0.9	9.5	-9.5		-9.5
25.	3.9	5.8	1.9	22.5	22.5	22.5	
26.	6.2	7.4	1.2	17.5	17.5	17.5	
27.	6.4	7.5	1.1	14.5	14.5	14.5	
28.	4.0	7.4	3.4	24.0	24.0	24.0	
Total				300.0		120.5	179.5

Table 6.40 Preferred Levels of Automation for the Selection Function.
(Skilled operators : 1-16, Unskilled operators : 17-28) (n=24).

c) Differences between preferred levels of automation in set-up functions before and after the FBS experiments for skilled operators.

From Table 6.41 and by Wilcoxon matched-pairs signed ranks Test. Tobt. = 28.5 > Tcrit. = 21.0 at alpha = 0.05 for a Two-tailed test. The result is non-significant and it fails to reject H_0. It is concluded that there is no difference between the preferred level of automation for set-up functions before and after the FBS experiments for skilled operators.

Subject	Qbef	QAft	Diff.	Rank	Signed Rank	Sum +ve	Sum -ve
1	5.0	4.8	-0.2	3.0	-3.0		-3.0
2	9.7	10.0	0.3	5.0	5.0	5.0	
3	1.1	1.4	0.3	5.0	5.0	5.0	
4	2.2	1.0	-1.2	12.0	-12.0		-12.0
5	2.4	1.0	-1.4	13.0	-13.0		-13.0
6	6.4	5.3	-1.1	11.0	-11.0		-11.0
7	8.1	8.0	-0.1	1.5.0	-1.5		-1.5
8	1.0	1.0	0				
9	5.5	3.7	-1.8	14.0	-14.0		-14.0
10	1.0	1.0	0				
11	6.5	5.8	-0.7	7.5	-7.5		-7.5
12	9.2	9.5	-0.3	5.0	-5.0		-5.0
13	9.1	8.2	-0.9	9.5	-9.5		-9.5
14	5.6	6.5	0.9	9.5	9.5	9.5	
15	4.2	4.3	0.1	1.5	1.5	1.5	
16	5.3	6.0	0.7	7.5	7.5	7.5	
Total						28.5	76.5

Table 6.41. Preferred levels of automation for set-up functions for skilled operators.

d) Differences between preferred levels of automation in set-up functions before and after the FBS experiments for skilled and unskilled operators.

From Table 6.42 and by Wilcoxon matched-pairs signed ranks Test. Tobt. = 117 > Tcrit. = 98 at alpha = 0.05 for a Two-tailed test. The result is non-significant and it fails to reject H_0. It is concluded that there is no difference between the preferred level of automation for set-up functions before and after the FBS experiments for skilled and unskilled operators.

Subject	QBef	QAft	Diff.	Rank	Signed Rank	Sum +ve	Sum -ve
1.	5.0	4.8	-0.2	3.5	-3.5		-3.5
2.	9.7	10.0	0.3	6.0	6.0	6.0	
3.	1.1	1.4	0.3	6.0	6.0	6.0	
4.	2.2	1.0	-1.2	19.5	-19.5		-19.5
5.	2.4	1.0	-1.4	21.0	-21.0		-21.0
6.	6.4	5.3	-1.1	17.5	-17.5		-17.5
7.	8.1	8.0	-0.1	1.5	-1.5		-1.5
8.	1.0	1.0	0				
9.	5.5	3.7	-1.8	23.0	-23.0		-23.0
10.	1.0	1.0	0				
11.	6.5	5.8	-0.7	9.5	-9.5		-9.5
12.	9.2	9.5	-0.3	6.0	-6.0		-6.0
13.	9.1	8.2	-0.9	13.0	-13.0		-13.0
14.	5.6	6.5	0.9	13.0	13.0	13.0	
15.	4.2	4.3	0.1	1.5	1.5	1.5	
16.	5.3	6.0	0.7	9.5	9.5	9.5	
17.	4.9	5.7	0.8	11.0	11.0	11.0	
18.	6.4	5.8	-0.6	8.0	-8.0		-8.0
19.	5.8	6.7	0.9	13.0	13.0	13.0	
20.	6.2	4.6	-1.6	22.0	-2.0		-2.0
21.	6.8	5.6	-1.2	19.5	-9.5		-9.5
22.	5.5	6.5	1.0	15.5	15.5	15.5	
23.	7.7	5.5	-2.2	24.5	-24.5		-24.5
24.	6.3	4.1	-2.2	24.5	-24.5		-24.5
25.	5.8	4.7	-1.1	17.5	-17.5		-17.5
26.	5.0	6.0	1.0	15.5	15.5	15.5	
27.	7.9	7.7	-0.2	3.5	-3.5		-3.5
28	4.7	7.1	2.4	26.0	26.0	26	
Total					351.0	117.0	234.0

Table 6.42. Preferred levels of automation for set-up functions for skilled and unskilled operators. (Skilled operators : 1-16, Unskilled operators : 17-28). (n=26).

e) Differences between preferred levels of automation in inspection functions before and after the FBS experiments for skilled operators.

Subject	QBef	QAft	Diff.	Rank	Signed Rank	Sum +ve	Sum -ve
1	1.0	1.0	0				
2	10.0	10.0	0				
3	1.0	1.0	0				
4	1.0	1.0	0				
5	1.0	1.0	0				
6	8.6	7.6	-1.0	4.0	-4.0		-4.0
7	6.0	8.4	2.4	7.0	7.0	7.0	
8	1.0	1.0	0				
9	6.4	4.6	-1.8	6.0	-6.0		-6.0
10	1.0	1.0	0				
11	3.4	2.8	-0.6	2.5	-2.5		-2.5
12	9.8	9.6	-0.2	1.0	-1.0		-1.0
13	7.2	6.6	-0.6	2.5	-2.5		-2.5
14	4.4	5.6	1.2	5.0	5.0	5.0	
15	2.6	2.6	0				
16	10.0	10.0	0				
Total						12.0	16.0

Table 6.43. Preferred levels of automation for inspection functions for skilled operators.

From Table 6.43, by Wilcoxon matched-pairs signed ranks Test, Tobt.=12 >Tcrit.= 2, at alpha = 0.05 for a Two-tailed test. The result is non-significant and it fails to reject H_0. It is concluded that there is no difference between the preferred levels of automation for inspection functions before and after the FBS experiments for skilled operators.

f) Differences between preferred levels of automation in inspection functions before and after the FBS experiments for skilled and unskilled operators.

From Table 6.44, by Wilcoxon matched-pairs signed ranks Test, Tobt.= 71 >Tcrit.= 46 at alpha = 0.05 for a Two-tailed test. The result is non-significant and it fails to reject H_o. It is concluded that there is no difference between the preferred levels of automation for inspection functions before and after the FBS experiments.

Subject	QBef	QAft	Diff.	Rank	Signed Rank	Sum +ve	Sum -ve
1.	1.0	1.0	0				
2.	10.0	10.0	0				
3.	1.0	1.0	0				
4.	1.0	1.0	0				
5.	1.0	1.0	0				
6.	8.6	7.6	-1.0	5.5	-5.5		-5.5
7.	6.0	8.4	2.4	17.5	17.5	17.5	
8.	1.0	1.0	0				
9.	6.4	4.6	-1.8	15.0	-15.0		-15.0
10.	1.0	1.0	0				
11.	3.4	2.8	-0.6	3.0	-3.0		-3.0
12.	9.8	9.6	-0.2	1.0	-1.0		-1.0
13.	7.2	6.6	-0.6	3.0	-3.0		-3.0
14.	4.4	5.6	1.2	8.5	8.5	8.5	
15.	2.6	2.6	0				
16.	10.0	10.0	0				
17.	6.6	8.0	1.4	11.5	11.5	11.5	
18.	5.0	6.0	1.0	5.5	5.5	5.5	
19.	5.4	3.2	-2.2	16.0	-16.0		-16.0
20.	2.8	4.4	1.6	13.5	13.5	13.5	
21.	6.0	7.2	1.2	8.5	8.5	8.5	
22.	10.0	1.0	-9.0	19.0	-19.5		-19.5
23	3.6	4.2	-0.6	3.0	-3.0		-3.0
24.	7.2	6.0	-1.2	8.5	-8.5		-8.5
25.	2.0	3.2	1.2	8.5	8.5	8.5	
26.	3.0	4.6	1.6	13.5	13.5	13.5	
27.	6.0	8.6	2.6	18.0	18.0	18.0	
28.	2.4	3.8	1.4	11.5	11.5	11.5	
Total				190.0		119.0	71.0

Table 6.44. Preferred levels of automation for inspection functions.

(Skilled operators : 1-16, Unskilled operators : 17-28) (n = 19)

g) Preferred level of automation by subjective evaluations for skilled operators.

Subject	Selection	Set-up	Inspection
1	2.95	4.90	1.00
2	10.00	9.85	10.00
3	1.10	1.25	1.00
4	1.50	1.60	1.00
5	1.55	1.70	1.00
6	5.60	5.85	8.10
7	8.45	8.05	7.20
8	1.00	1.00	1.00
9	5.70	4.60	5.50
10	1.00	1.00	1.00
11	5.70	6.15	3.10
12	1.00	9.35	9.70
13	5.35	8.65	6.90
14	9.35	6.05	5.00
15	7.20	4.25	2.60
16	6.75	5.65	10.00
Total	74.2	79.9	74.10
Mean	4.64	5.00	4.63

Table 6.45. The mean values of preferred levels of automation by subjective evaluations for skilled operators.

It was observed that (from Table 6.33) that there is no difference between the values of PLA before and after the FBS experiments. Therefore, subsequent analyses are carried out using the mean values of PLA.

However analysis (Tables 6.39, 6.40, 6.41, 6.42, 6.43 and 6.44) showed that there is no difference between the results before and after the FBS experiment. Therefore the mean values of PLA could be taken for each human selection, set-up and inspection functions. From Tables 6.45 and 6.46 for the selection and set-up functions, the preferred levels of automation are both 6.0 for skilled and unskilled operators (both 5.0 for skilled operators), and for the inspection function the value is 5.0 (5.0 for skilled operators).

h) Preferred level of automation by subjective evaluations for skilled and unskilled operators.

Subject	Selection	Set-up	Inspection
1.	2.95	4.90	1.0
2.	10.00	9.85	10.0
3.	1.10	1.25	1.0
4.	1.50	1.60	1.0
5.	1.55	1.70	1.0
6.	5.60	5.85	8.1
7.	8.45	8.05	7.2
8.	1.00	1.00	1.0
9.	5.70	4.60	5.5
10.	1.00	1.00	1.0
11.	5.70	6.15	3.1
12.	1.00	9.35	9.7
13.	5.35	8.65	6.9
14.	9.35	6.05	5.0
15.	7.20	4.25	2.6
16.	6.75	5.65	10.0
17	2.90	5.30	7.3
18.	4.05	6.10	5.5
19.	4.70	6.25	4.3
20.	5.85	5.40	3.6
21.	4.95	6.20	6.6
22.	6.35	6.00	5.5
23.	5.85	6.60	3.9
24.	6.65	5.20	6.6
25.	6.55	5.25	2.6
26.	5.25	5.50	3.8
27.	4.85	7.80	7.3
28.	6.80	5.90	3.1
Total score	144.90	151.50	134.2
Mean PLA	5.18	5.41	4.8

Table 6.46. The mean values of preferred levels of automation by subjective evaluations for skilled and unskilled operators.

It could be observed that, generally, both skilled and unskilled operators portray central tendencies and tend to avoid the two extremes of fully manual or fully automated system.

6.10.3. Summary of the findings of objective 6

The findings obtained by Wilcoxon tests on the differences between the preferred levels of automation in the overall, selection, set-up and inspection functions are summarised in the flow chart shown as Figure 6.35.

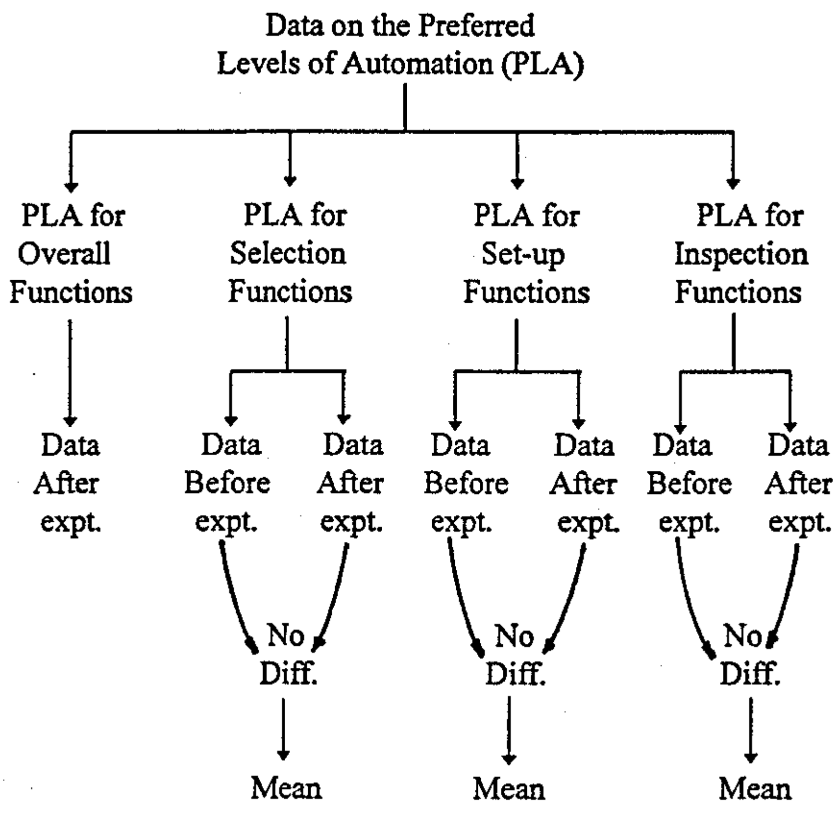


Figure 6.35 Flow chart showing a summary of the differences between the preferred levels of automation for selection, set-up and inspection functions before and after the FBS experiments.

6.11. Subjective Evaluations of Operators' Opinions With Regard to Mismatches

Based on given alternatives in the questionnaire, the operators' opinions were collected for the reasons for mismatches, the effects of mismatches on production and suggestions to reduce or prevent mismatches in machining operations. The aim was to determine views from operators' perspectives on the current issues regarding mismatches so that measures could be taken to resolve the problems. Responses collected from the questionnaires after the FBS experiments are analysed because it has been established earlier that this questionnaire is more reliable (see Section 6.5.1.2.(c)) and these are given below:

6.11.1. Reasons for the Occurrence of Mismatches

(Refer Table 6.47)

Reasons	Skilled operators	Unskilled operators
a. Some operators are less knowledgable about machining tasks	3	7
b. Careless mistakes	13	6
c. Operators are less well-trained.	5	4
d. Pressure to complete jobs on time.	9	7
e. Other reasons.	0	0

Table 6.47 Reasons for mismatches by skilled and unskilled operators.

With reference to Figure 6.36 and according to skilled operators, the most common reasons for mismatches are "careless mistakes" and "pressure to complete jobs on time". Inadequate training and lack of knowledge are the least likely reasons given. In contrast, unskilled operators cite inadequate training and lack of knowledge as the most common reasons for mismatches while the least likely reasons are "careless mistakes" and "pressure to complete jobs on time".

By and large, the findings suggest that there are significant differences between the reasons given by skilled operators and those given by unskilled operators with regard to mismatches in machining operations.

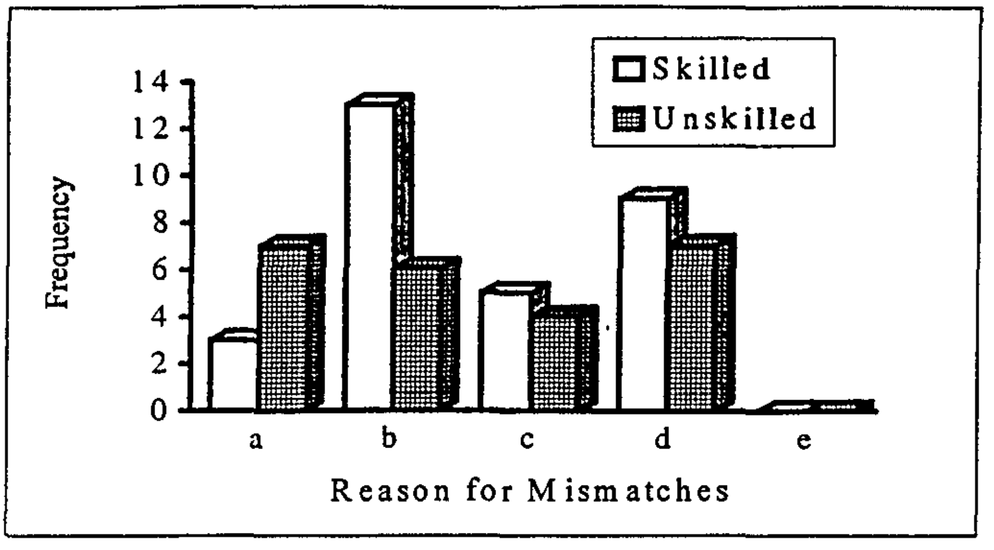


Figure 6.36 Reasons for the occurrence of mismatches

6.11.2. Effects of Mismatches on Production
(Refer Table 6.48)

The two most common effects of mismatches on production given by skilled operators were "production delays" and "scrap work" while responses by unskilled operators were mainly production delay and scrap work (loss of quality in production). These are shown in Figures 6.37. Finding suggests that operators are convinced of the negative aspects of mismatches on machining.

Effects of mismatches	Skilled operators	Unskilled operators
a. Production delay	8	7
b. Scrap work	9	6
c. Loss of materials	2	2
d. Loss of precious man-hours	6	3
e. Loss of quality in production	6	6
f. No apparent effects	1	0
g. Other effects.	0	0

Table 6.48. Response on the effects of mismatches by skilled and unskilled operators

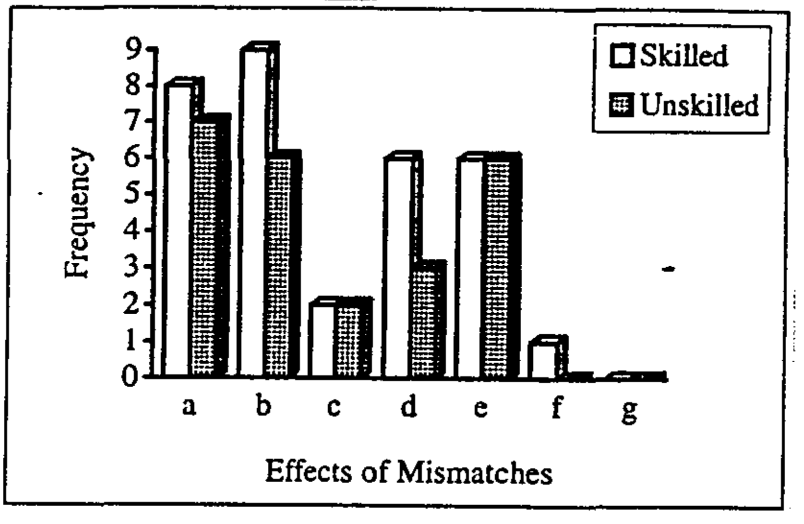


Figure 6.37. Effects of mismatches on production

6.11.3. Suggestions to Reduce or Prevent Mismatches
(Refer Table 6.49)

Skilled operators suggested the improvement of instruction aids and special monitoring procedures in an effort to prevent or reduce the occurrence of mismatches as shown in Figure 6.38. Beside suggestions through the improvement of machining instruction aids, unskilled operators provided frequent retraining as a means of reducing mismatches. Both skilled and unskilled operators had almost similar opinions with regard to efforts to reduce or prevent mismatches.

Particulars	Skilled operators	Unskilled operators
a. Frequent re-training	6	9
b. Improvement in machining instruction aids	11	7
c. Special monitoring procedure for machining operations.	9	6
d. Mismatches are beyond preventive measures	3	1
e. Other suggestions	1	1

Table 6.49. The frequency of responses for suggestions with regards to the occurrence of mismatches

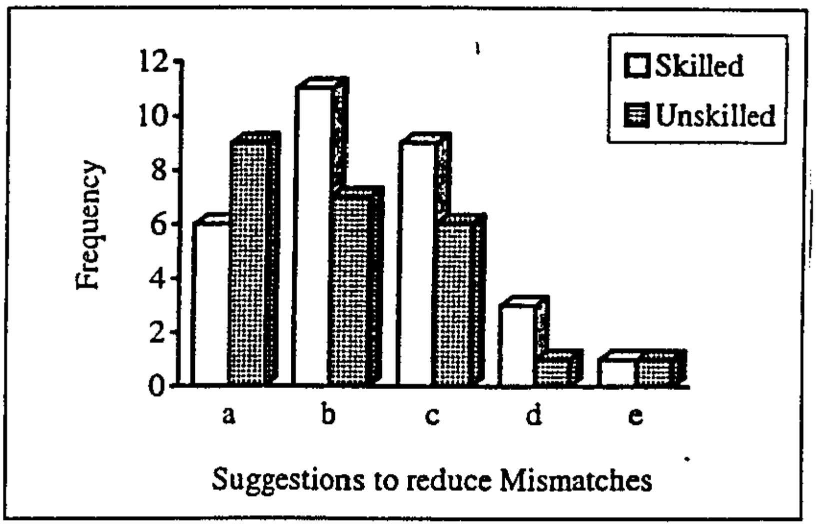


Figure 6.38 Responses on the suggestions to improve or reduce the occurrence of mismatches

6.12. Reliability and Validity

6.12.1. Intra-observer Reliability

Video recordings of machining operations to produce the sample component (Figure 5.2) by each of four subjects were carried out to establish the intra-observer reliability of the field-based simulated experiments. During machining mismatches were observed live and recorded by the experimenter. The machining tasks were later reviewed on a replay and the mismatches were observed and recorded again. There was some considerable difference of the number of mismatches collected using the two observation methods.

With reference to Table 6.50, it is observed that the percentage differences between mismatches obtained by live and video observations are between 14.5 % and 19.0%.

Mismatches	Subject 1	Subject 2	Subject 3	Subject 4
i) From live observation	43.0	48.0	35.0	30.0
ii) From video observation	37.0	39.0	29.0	25.0
iii) % difference [(i) - (ii)]	14.5	19.0	17.0	17.0

Table 6.50 Mismatches obtained from live and video observations on random subjects

6.12.2. Validity

Evidence of mismatches was obtained from structured observation of the experiments (FBS), operators' self-assessment from questionnaire responses before and after FBS experiments and observation on actual machining work by an operator. Even though the data shows varying trends between the different techniques, the results conclude that mismatches are inherent to operators and need investigation.

Self-confidence, level of trust and preferred levels of automation are typical human characteristics, measures of which are obtained by self-assessment. The results suggest that both skilled and unskilled operators showed consistency in assessing their self-confidence and trust as demonstrated by the questionnaire responses before and after the FBS experiments.

However, the preferred levels of automation were not consistent and the results obtained from the questionnaire after the FBS experiments were used in the analysis because prior and immediate experience from the experiments might have influenced the subjects' own self-assessment of their preferences.

6.13. Summary of Findings

6.13.1. Results of tests

Results of the tests is shown in Table 6.51. (Accepted hypothesis is marked H_1 or H_o). Results of tests include the hypothesis testings, the comparison between pairs of variable collected in questionnaire survey, establishing relationships between variables for questionnaires before and after the experiments.

Hypotheses	Hypothesis accepted	
	Skilled and unskilled operators	Skilled operators
H1 The higher the skill level of operators, the fewer mismatches are committed.		
i) Field-based simulated experiments		
a) Mann-Whitney U Tests (overall)	H_1	
b) Mann-Whitney U Tests (selection functions)	H_1	
c) Mann-Whitney U Tests (set-up functions)	H_1	
d) Mann-Whitney U Tests (inspection functions)	H_1	
ii) Questionnaires before and after FBS experiments		
a) Spearman's correlations		
-before FBS experiments	H_o	H_o
-after FBS experiments	H_o	H_o
b) Wilcoxon matched-pairs signed ranks Test		H_1
c) Mann-Whitney U Tests :		
-before FBS experiments	H_o	

-after FBS experiments	H_o	
1.2. For selection functions		
Questionnaires before and after FBS experiments		
a) Wilcoxon matched-pairs signed ranks test :		H_1
(unskilled category : H_1)		
b) Mann-Whitney U Tests :		
-before FBS experiments	H_o	
-after FBS experiments	H_o	
1.3. For set-up functions		
Questionnaires before and after FBS experiments		
a) Wilcoxon matched-pairs signed ranks test :		H_o
(unskilled category : H_1)		
b) Mann-Whitney U Tests :		
-before FBS experiments	H_o	
-after FBS experiments	H_o	
1.4. For inspection functions		
Questionnaires before and after FBS experiments		
a) Wilcoxon matched-pairs signed ranks test :		H_o
(unskilled category : H_1)		
b) Mann-Whitney U Tests :		
-before FBS experiments	H_o	
-after FBS experiments	H_o	
H2 Operators having high self-confidence commit less mismatches.		
a) Wilcoxon matched-pairs signed ranks test :		H_o
(unskilled category : H_o)		

b) Spearman correlation	H_1	H_o
H3 Operators having high level of trust commit less mismatches.		
a) Wilcoxon matched-pairs signed ranks test :		H_o
(unskilled category : H_o)		
b) Spearman correlation :	H_1	H_o
H4 The longer the working experience the fewer mismatches committed.		
a) Spearman correlation :	H_1	H_o
H5 The higher the age of operators, the fewer mismatches committed.		
a) Spearman correlation	H_1	H_o
H6 The higher the skill level of operators, the higher their self-confidence.		
a) Mann-Whitney U Tests :	H_1	H_o
H7 The higher the self-confidence, the higher their level of trust.		
a) Spearman Correlation	H_1	H_1
H8 The longer the working experience, the higher the self-confidence.		
a) Spearman Correlation	H_1	H_o
H9 The higher the age of operators, the higher their self-confidence.		

a) Spearman Correlation:	H_1	H_o
H10 The higher the skill level of operators, the higher the level of trust.		
a) Mann-Whitney U Tests :	H_1	H_o
H11 Operators having longer working experience show higher levels of trust.		
a) Spearman Correlation:	H_o	H_o
H12 The higher the age of operators, the higher the level of trust.		
a) Spearman Correlation:	H_o	H_o
H13 Operators who prefer higher levels of automation, commit less mismatches.		
i) Questionnaires before and after FBS experiments		
a) Wilcoxon matched-pairs signed ranks test :	H_1	H_o
(unskilled category : H_1)		
ii) Mann-Whitney U Tests :	H_1	H_o
H14 Skilled operators prefer lower levels of automation.		
i) Mann-Whitney U Tests :	H_o	H_o
H15 Operators having high self-confidence prefer lower levels of automation.		
a) Spearman Correlation:	H_o	H_o
H16 Operators having a higher level of trust prefer a lower level of automation.		

a) Spearman Correlation:	H_o	H_o
H17 Operators having longer working experience prefer lower level of automation		
a) Spearman Correlation:	H_o	H_o
H18 Older operators prefer lower levels of automation.		
a) Spearman Correlation:	H_o	H_o

Table 6.51 Summary of Results of Tests

6.13.2. Sixth Objective : Establishing the levels of automation preferred for the overall, selection, setting-up and inspection functions.

The overall preferred levels of automation for both skilled and unskilled categories of operators is between the levels of 5 and 7.

The preferred levels of automation by both skilled and unskilled operators for the specific functions are as below :

Selection functions : Level 6

Set-up functions : Level 6

Inspection functions : Level 5

6.14. Conclusion

Analyses were carried out using the statistical techniques Wilcoxon match-pairs rank, Mann-Whitney U, Spearman's correlations and chi-square tests on the data obtained by the FBS experiments and the questionnaire surveys.

The findings suggest that there are differences between mismatches obtained by experiments compared to those obtained by surveys, and between mismatches obtained by surveys before and after experiments. Compared with the survey before the experiments, there is also evidence that the results of the survey after the experiments has a higher correlation to the experimental results. As such, further analyses were carried out using results obtained by experiments while in other circumstances the results of the survey after the experiments were used.

In contrast to the preferred levels of automation, there is evidence that the variables of self-confidence and trust show no differences between surveys before and after experiments. Mean values for self-confidence and trust, and data by survey after experiments for preferred levels of automation were used in subsequent analyses. Under natural circumstances skill, work experience and age do not show any variation.

Results for the combined group of skilled and unskilled operators indicate that significant relationships were established between mismatches and self-confidence, trust and age; between self-confidence and skill, trust and age; between trust and skill, work experience and age, and between preferred levels of automation and mismatches.

However, the study showed that there were no significant relationships between mismatches and skill categories and work experience; between self-confidence and work experience, and between preferred levels of automation and skill, self-confidence, trust, work experience and age.

Meanwhile, for skilled operators results indicate that a significant relationship was established between self-confidence and trust but an absence of relationships between mismatches and skill, mismatches and self-confidence, mismatches and trust, mismatches and work experience and mismatches and age, self-confidence and skill, self-confidence and work experience, self-confidence and age, trust and skill, trust and work experience, trust and age, preferred level of automation and mismatches, preferred level of automation and skill, preferred level of automation and self-confidence, preferred level of automation and trust, preferred level of automation and working experience, and preferred level of automation and age.

The general conclusion is that there are relationships between performance and particular human characteristics for the cross-section of skilled and unskilled operator in machining tasks. The findings show that subjectively evaluated operator preferences for levels of automation have also been determined by questionnaire survey.

A more detailed discussion of the findings is presented in Chapter Seven.

CHAPTER 7

DISCUSSION OF EMPIRICAL RESULTS

7.1. Introduction

This chapter highlights and discusses issues identified in the relationships between variables and the techniques employed in the investigation, i.e. the field-based simulated experiment and questionnaire survey. These were analysed for possible relationships and related to the literature. Consistencies and conflicts are also identified and discussed based on major issues in the literature, research hypotheses and results.

The first major part of the discussion emphasises the suitability of the human task mismatch matching method followed by the relationships between variables which formed the crux of this study. Comparisons between findings in the current study and by other researchers are also provided. The final part of this chapter emphasises the preferred levels of automation and the generalisation of the research findings.

7.2. Suitability of the Human Task Mismatch Matching Method

The suitability of the Human Task Mismatch Matching Method is discussed to confirm the reliability and validity of the results. Discussions are based on the following :

i) sample size
ii) prevention of bias
iii) reliability
iv) validity

7.2.1. Sample size

The present study generated a statistically adequate amount of data although a larger range and quantity of subjects would have been useful. A larger sample size would possibly have resulted in greater confidence in the rejection of hypotheses. The rejected hypotheses are mainly concerned with the subjective factors of trust and preferred levels of automation which are difficult to measure within small groups. However, these data were justified and able to meet the specified objectives by analysis using the Wilcoxon and Mann-Whitney U tests.

Limited sample size is a problem that is frequently found in studies of this nature (e.g. 6 subjects for Scallen et al (1995), 8 subjects for Pratt and Corlett (1970), 16 subjects for Seppala and Salvendy (1985), 24 subjects for Kragt (1984) and 29 subjects for Beach and Tennant, (1992)). A small number of subjects volunteered to take part in the research and despite considerable recruitment effort and payment incentives the study was limited to 28 subjects. The common characteristics of the subjects were that they were all British male, had some knowledge (from little to extensive) of turning operations on manual centre lathes and their willingness becoming subjects in the investigations.

7.2.2. Prevention of Bias

Bias is an influence involving unwanted or uncontrolled elements that could possibly affect the outcome or produce expectations as to the results of an investigation or study. Bias needs to be reduced or compensated for in obtaining uncontaminated data, hence producing acceptable results.

In the procedure, each subject completed a questionnaire followed immediately by the FBS experiment. On completion of the experiment, a further questionnaire (identical to the first) was completed by the same subject. This was done without refering to the first questionnaire, and furthermore subjects were unaware of the outcome of the FBS experiment. This immediate succession of the three elements of the study reduced bias by removing any opportunity for subjects to be influenced by external factors in reaching subjective judgements.

7.2.3. Reliability

Intra-observer reliability measures were obtained for the FBS experiments. Generally, observers need prior background knowledge and expertise in turning operations on centre-lathes for effective observations. In an attempt to gain a measure of reliability the direct observations were supplemented by video which was analysed subsequent to the experiments.

Several limitations are inherent in the technique of observation of videos compared to live observation. Since one camera was used, it provided only one angle of view of the turning operation under study, and this could lead to unobserved events.

Pictures were not particularly sharp and machining tasks were not obvious and identifiable on films. Some momentary actions were not recorded and filming efficiency was rather critical in achieving reasonable results. Lighting was poor in the workshop situation and tools were not identifiable.

Contingency actions were essential to improve observations from the video. Observations should thus concentrate on the moving parts of the machine (e.g. saddle) in addition to the actual operating actions. Parts of machine (tools, levers, wheels, etc) used by subjects might provide clues as to what actually went on during the turning operations.

In this study, an acceptable level of intra-observer reliability was achieved without a perfect match between live and video observations. Quantitative details have been discussed in section 6.12.1. However, in future investigations some improvement is essential to improve results.

7.2.4. Validity of the Variables

i) Mismatches

In the current study, mismatches were generated from field-based simulated (FBS) experiments together with questionnaires survey before and after the FBS experiments. Results from a sample study (section 5.11.2.) prove that the variable is an inherent factor to humans in machining operations. It is also observed that the techniques (i.e. observation on the FBS experiments, questionnaire surveys and observation on the shopfloor) are qualitatively complementary.

ii) Self-confidence, Level of Trust and Preferred Levels of Automation

These variables were generated from questionnaire responses before and after the FBS experiments. For both self-confidence and level of trust, analysis suggests no significant differences between the responses before and after the FBS experiments. Therefore, the variables are considered valid in the investigation and hence, the use of mean values in the analysis.

Meanwhile, significant differences are shown between the questionnaire responses before and after the FBS experiment for the preferred levels of automation. This indicates that the questionnaire responses after the FBS experiments do not validate those obtained before the FBS experiments. In this particular case, the use of the results of PLA after the FBS experiments are used in the analysis.

7.3. Relationships between Variables

Each of the hypotheses has been explained in Chapter Six in relation to the results obtained and the findings for the particular relationships. Explanation of the findings has been made with reference to the literature and the formulation of the hypotheses. Information has been derived from the relationships between mismatches and preferred levels of automation and basic human characteristics which do not appear in previous research.

7.3.1 Mismatches

It is reiterated that mismatches should not occur for successful execution of jobs. Zero mismatches by human operators might be idealistic but this remains as the aim of designers of automated systems that shift the roles of humans on to machines.

i) Mismatches and skill

The results show that skilled operators commit fewer mismatches compared to unskilled operators. The relationship between mismatches and skill provides the evidence to establish the effect and extent of mismatches committed by the different skill categories specifically for machining operations on manual centre lathes. Further, it was found that skilled operators suffered more from "repeating procedures" while the unskilled operators were more prone to "requiring assistance".

Skill is a product of extensive training, long-term exposure to manufacturing processes and frequent execution of similar machining tasks. Hence mismatches have profound effects on learning and training. Findings from the investigation revealed that repetition constitutes 72.0 % of mismatches committed by skilled operators, and that these result from mechanical failures including mechanical engagement (e.g. selecting speed by engaging levers), parts assembly (e.g. set-up tools on tool posts) and problems in manual aspects of machining processes (e.g. tools selection, replacement or resharpening).

The repetition mismatch is considered significant in the sense that the design and handling of mechanical parts requires improvements from both the technological and ergonomics perspectives. From a technological perspective, design, accuracy and durability of component parts should be improved. Meanwhile from the ergonomics perspective, user aspects should be considered to provide for better handling in set-up and selection functions so that time losses could be reduced to the benefit of productivity.

Mismatches are corrected actions that could be reduced considerably provided the causes and consequent actions are identified. Basically, options for reducing mismatches are reduced to selecting either semi-automated or fully-automated machining considering the incapability of human operators to perform machining tasks without mismatches. For example in speed selection a semi-automatic solution would be the provision of a number pre-selected speeds each with its own control (e.g. a press button). A fully-automated solution to the same problem would be a highly intelligent control system that was capable of adapting to changing cutting conditions. Clearly, the relative costs of these two alternatives needs consideration alongside their relative ability to reduce mismatches.

Parts assembly could be improved by readily assembled relevant parts (e.g. in turret lathes) or a bank of assembled parts within the specified working area. The relatively large numbers of mismatches associated with set-up tools and parts, indicate that current developments in pre-set tool design and universal parts loading systems should be pursued to reduce these mismatches.

The problems of manual aspects of machining processes are not easily reduced or eliminated because tool-workpiece interaction is involved where several factors (e.g. tool life, tool sharpness, etc.) should be considered. These problems persist in manual and automated machining processes. However, technological developments such as the use of self-sharpening cutting tools could provide a solution to some of the problems. Ordinary tools may break off so machining is interrupted, but a broken self-sharpening tool would leave a cutting edge that could continue cutting to produce a surface finish to an acceptable standard.

Mismatches have negative characteristics due to the unfulfillment of the purpose in executing specific tasks. Unskilled operators committed higher occurrences of mismatches due to lower anticipation which is known to be important for skilled performance (Holding, 1981). Lower anticipation results from inadequate training exposure for unskilled operators while over-confidence is likely to be the prime reason for skilled operators.

The findings should be useful for micro-analysis of training requirements especially those involving machining operations in manufacturing, and the identification of mismatches may help to avoid or reduce down-time (Chadwick-Jones, 1969). The results provide a comprehensive view of the effects of mismatches in human-machine interaction that has not been available from earlier studies.

ii) Mismatches and self-confidence

The results show that there was a significant relationship between mismatches and self-confidence for the combined skilled and unskilled category of machine operators in turning operations; the greater the self-confidence, the less the mismatches. It was also established that, there was no evidence of a relationship between self-confidence before and after the experiments for either skilled or unskilled operators, indicating that their self-assessments are reliable.

However results indicate an absence of a relationship between mismatches and self-confidence for skilled operators which implies that the two variables are independent of each other. Skilled operators are well-trained and will have gained in self-confidence over many years experience of handling mismatches. This implies that self-confidence alone is not a strong contributor to the occurrence of mismatches and suggests that other human characteristics should be considered when mismatches are discussed.

The findings provided a quantification of the relationship that is not found in previous studies. Skilled operators have high self-confidence due to their skill and training and this allows them to commit fewer mismatches with the reverse being true for unskilled operators.

Generally, self-confidence refers to the prevalence of certainty. Even though it is dynamic and unpredictable, it is not inherent to every operator and this is consistent with the obvious and generally well-accepted views. Understanding the relationship between mismatches and self-confidence through identification and analysis of mismatches should prove useful in the development of training programmes and machine or system design.

iii) Mismatches and level of trust

Testing of the hypothesis showed that a relationship is evident between the occurrence of mismatches and trust; the greater the trust, the less the mismatches. Further, there was no evidence of a difference between the scores for trust before and after the experiments for either skilled or unskilled operators which suggests that like self-confidence, trust is an inherent human factor. The negative correlation between mismatches and trust corresponds to the findings of Lee and Moray (1992) who suggested that system performance and occurrence of faults could affect trust.

The absence of a relationship between mismatches and trust for skilled operators indicates that trust alone does not contribute to the occurrence of mismatches. However, results from all the skilled operators showed consistent responses which imply that mismatches and trust are inherent variables in machining operations.

Trust can be developed through experience, training and familiarisation. This indicates the importance of careful planning by the organisation in its technology acquisition, and of attention to human resource programmes. However, training should not over-emphasise experience and familiarity since a sub-maximal level of trust is sufficient to prepare workers for performing machining operations. However, other potential parameters such as sociological aspects may be significant and worthy of investigation in this context.

iv) Mismatches and work experience

The results of the combined group of skilled and unskilled operators establish that there is a negative correlation between mismatches and working experience which suggests that operators with longer work experience commit less mismatches. This finding formally establishes the benefit arising from the long hard work experienced by skilled operators. However, complacency should be avoided and efforts made to face the challenge of achieving low mismatches with short working experience.

Results for the skilled operators indicate a non-significant relationship between mismatches and work experience but the results imply that lower mismatches correspond to longer work experience. This is consistent with the findings obtained for the combined group of skilled and unskilled operators.

v) Mismatches and age

Testing of the hypothesis showed that there is evidence of a relationship between mismatches and age for the combined group. The results indicate that the higher the age of the operators, the lower the occurrence of mismatches. This contradicts the findings of Kay (1958) and Welford (1958) who thought that errors would increase with age and the difficulty of tasks.

Meanwhile skilled operators fail to show a significant relationship between mismatches and age in machining operations but results are consistent with the findings for the combined group. This implies that older operators commit fewer mismatches than their younger colleagues.

Under normal circumstances, age is synonymous with maturity which is a factor in human capability. However, the findings are limited to the focussed age group of operators who were the subjects in the study i.e. between 20 and 55 years of age (i.e. of working age).

Bearing in mind such findings, machine design should include an analysis of the controls and job aids that would possibly benefit younger operators performing machining tasks in order to achieve a mismatch-free work situation.

7.3.2. Self-confidence

Self-confidence refers to the feeling of certainty. Being a subjective characteristic of human operators, the element could best be explained in terms of its relationships with other identified variables. Self-confidence is one of the attributes of the successful execution of tasks and should not remain unexploited. Tests indicate that there is no difference between the score of self-confidence before and after the experiments.

i) Self-confidence and skill

Significant results from the hypothesis testing indicate that there is a relationship between skill level and self-confidence. Skill may instill high self-confidence among machine operators and may be attributed to experience and training. It is thus necessary to maintain skill simply for the sake of maintaining self-confidence.

Skill could be maintained by training or by design of hardware. Training may involve refresher courses and provide continuity of skill maintenance. Design of hardware should reduce automation where it could adversely operators' mental stress (Ekkers et al, 1979). Instead, mental stimulation is needed to enhance the appropriate level of automation to satisfy the above phenomenon.

ii) Self-confidence and level of trust

It has been suggested that mistrust would cause inappropriate task allocation strategies and influence operators' reliance (Lee and Muir, 1994). Therefore, operators' trust on machines needs to develop in parallel to that of their self-confidence.

Analysis by the Spearman correlation method for the combined group of skilled and unskilled operators suggests that operators having higher levels of self-confidence have correspondingly high levels of trust in machines. The same relationship was found when considering only skilled operators. Empirically, it is observed that operators' self-confidence produces a good relationship with trust during manual control operations in machining. This is in line with the opinion of Lee and Moray, (1994) that trust influences operators' reliance in manual control.

Even though the relationship may be unilateral (i.e. machines do not have trust in humans), there is a strong indication that successful machining operations are attributed to these two important parameters of human-machine symbiosis.

iii) Self-confidence and working experience

Testing of the hypothesis for the combined group showed that the result is significant and a relationship is established between self-confidence and work experience, but the results indicate a non-significant relationship for skilled operators. Both imply that lower self-confidence corresponds to lower work experience.

This result provides empirical evidence which agrees with the commonly accepted and informal views that working experience instils self-confidence. The finding agrees with the suggestion by Silver et al (1995) that self-efficacy would cause, and might be caused by, performance experiences.

However, this concept should pave for the way to boost self-confidence among operators where possibly the extremes of the characteristic, lack of self-confidence and over self-confidence for either skilled or unskilled operators are detrimental to the execution of tasks.

iv) Self-confidence and age

In the absence of any formal studies which relate self-confidence to age in machining, a significant result was obtained in the hypothesis testing which suggests that there is a relationship between self-confidence and age for the combined group of machine operators.

The result is in parallel with the earlier finding (the relationship between mismatches and age) and emphasises that age is an important contributor towards the design of tasks and subsequently machine designs.

For the skilled operators, non-significant relationships are shown implying that younger operators have lower self-confidence.

Under normal situations, it could be observed that learning and experience might increase with age and instil self-confidence particularly where it involves psychomotor skills.

7.3.3 Level of Trust

Trust has always been associated with self-confidence (Lee and Moray, 1994). One may implicate the other to the extent that analysis of results or discussions would be incomplete in the absence of either. Moreover, trust influences the execution of tasks even though its subjective nature proves incomprehensible other than in its relationships with other identified variables.

For the combined group of skilled and unskilled operators, the result of the hypothesis test is significant and positive relationships are established between level of trust and skill but only non-significant relationships are found with work experience and age. This result is in parallel to the previous finding that high trust corresponds to lower mismatches. This finding has also confirmed the informal view that skill helps to develop trust in machining and supports the suggestion by Luhman (1980) that trust helps to reduce complexity and uncertainty.

However for skilled operators the hypothesis tests show non-significant results which imply that no relationships exist between trust and skill, trust and work experience and trust and age. For the relationship between trust and work experience, a high level of trust corresponds to lower work experience. A similar pattern of relationship could be observed between trust and age where a high level of trust corresponds to lower age. Such relationships may imply that skilled operators irrespective of their work experience and age show lesser reliance on machines and may prefer personal involvement with tasks in machining operations.

This concept should be exploited in manufacturing where machine designs need to cater for all types of operators. Training should be designed to enable operators, especially new and unskilled operators, to gain an adequate level of trust more easily and in a much reduced time as an aid to efficient production.

The absence of relationships between trust and work experience and trust and age suggest that trust does not naturally occur in older and more experienced workers. Instead, re-training and refresher courses are justified if only to reinforce the level of trust before experiencing a loss of trust that would be detrimental to production and their careers.

7.3.4. Preferred Levels of Automation

In this research the level of automation consisted of a notional scale which was used to show a range of levels of automation in a particular system. The scale ranges between fully manual (1) and fully automated (10). The scale was used as a reference to establish if there were relationships between the preferred levels of automation (PLA) and physical (mismatches and skill) and psychological (self-confidence, trust, working experience and age) human characteristics.

The scale was used in an attempt to determine the level of automation preferred by operators. This is essential considering that the broad spectrum of the level of automation is rather unspecific for both machine design and operator training procedures. The proper PLA is considered to be the basis on which to start the procedure of selecting the level of automation from a human perspective.

The results of hypothesis testing indicate that there is a relationship between PLA and mismatches but show the absence of relationships with other variables i.e. skill, self-confidence, trust, work experience and age.

Low mismatches corresponding to higher PLA agrees with Goldstein (1971) who suggested that working under preferred conditions resulted in proper execution of tasks with a feeling of comfort and ease. Under preferred levels of automation operators identify their roles more readily and this accordingly could explain the low occurrence of mismatches. In contrast, non-preferred levels of automation result in higher mismatches possibly due to the occurrence of unexpected or unplanned interruptions.

There is an absence of a relationship between skill and the preferred levels of automation. Findings suggest that preferences for levels of automation do not depend on the skill level of operators, and this can be attributed to the operators' level of competency resulting in less reliance on the machine especially in decision-making processes.

The lack of relationships between the preferred level of automation and self-confidence contradicts findings by Lee and Moray (1994) who suggested the use of automation when trust exceeds self-confidence and opt for manual control when self-confidence exceeds trust. Instead, the current findings suggest that operators having high self-confidence and trust might also prefer a high level of automation.

Furthermore, the absence of a relationship between PLA and trust, work experience and age may be due to operators' competency resulting in less reliance on machines to execute jobs. Even though a relationship between mismatches and age is not established, the finding supplements current information which relates age to system functions (Robinson et al, 1984) and automation as a major change for older workers (Coberly and Morrison, 1984).

From the operator's perspective, the absence of relationships (PLA and self-confidence, trust, work experience and age) suggest that operators' preferences are not related to the variables measured. However, it could be implied that automation (either low or high automation) may be viewed as unimportant to their tasks. In manufacturing, installing automation involves high capital costs that could be considered a waste if it is unacceptable to users. However, an optimum level of automation should be the ideal choice.

Since there are no significant relationships between PLA and self-confidence, trust and work experience and age, based on the current study it is concluded that automation is not of particular importance and has no effect on operators. However, it could be recommended that a system for turning operations should be designed with different levels of automation that could be selected by operators.

This is in line with prior findings (Drury and Goonetilleke, 1992) and (Drakeford and Hardy, 1994) who suggested that there was a decline in performance measures but an increase in stress with the increase in automation levels (except at the complete automation level) and concluded that consistent performance benefits were virtually absent (Drury and Goonetilleke, 1992). Meanwhile, Drakeford and Hardy (1994) reported an example of limited success of automation based on actual manufacturing processes.

7.4. Preferred Level of Automation Corresponds to Human Functions.

It has been shown that for skilled operators, higher mismatches occurred in the selection functions compared to the other functions under study (set-up and inspection). On the other hand, set-up functions were the source of higher occurrences of mismatches for unskilled operators.

Based on the analysis, there was no evidence of a difference between the preferred level of automation before and after the experiments for either skilled or unskilled operators which suggests that subjects remain consistent with their subjective opinion as to their preferences for the level of automation. The preferred level of automation generated by subjective evaluation for each function (i.e. selection, setting-up and inspection) corresponds to the overall value of preferred level of automation given by the subjects.

Generally, this research identifies the functions that require priority for automation. With respect to mismatches, selection and set-up functions should be given priority for automation over the inspection functions. Hence, it is suggested that automation of inspection functions should be at the mid-point of the scale (i.e. a PLA value of 5.0), whilst set-up and selection function might benefit from slightly higher levels of automation (i.e. a PLA value of 6.0).

7.5. Further Development of the Preferred Level of Automation.

7.5.1. Justification of the development of preferred level of automation

Decision-making for automation has previously largely been based solely on technological (software and hardware) or economic (competition, profit and material prosperity) criteria with little emphasis on the human perspective.

Currently, humans are indirectly made to fit into automation even though automation has limitations in several respects. One limitation involves the redesigning products to fit the requirements of automation by avoiding intricate shapes in the process called "Design for Automation" or "Design for Manufacturability" (Helander, 1994). Together with concurrent engineering they are but some of the implications of automation in manufacturing. Compatibility between humans and automation has in comparison received much less attention.

Rasmussen (1986) suggested that "it is important to develop methods and tools that allow a system designer, experimentally and analytically, to evaluate the match between his design intentions and the way the actual user(s) adapts to his system". This should be equally applicable to manual and automated equipment and systems.

It was a part of the intention of this research to develop an approach for the purpose of evaluating the match as suggested above. Although, the matching concerned was between the tasks expected and those performed by operators during turning operations, it is believed that this has implications in other areas, notably in determining suitable levels of automation.

The conclusions of the research may be used to enlighten the approach to determining the levels of automation in machining. The levels of automation are expected to provide a link between humans and automation. Lee and Moray (1992) have indicated that a treatment in this area is particularly necessary and would allow a continous link-up between human and automation. This research should provide the means for quantitative and qualitative evidence to enable this approach to take place.

In the current study, it was discovered that mismatches, level of self-confidence, trust and preference for levels of automation have implications for a number of human factors issues associated with the operator-machine interface. This was evident from the relationships established between variables in the field-based simulated study (field-based simulated experiments and questionnaire survey).

The research has established relationships between the preferred level of automation and mismatches. Recommendations for determining levels of automation should be based on mismatches because automation is directly involved with replacing human tasks to achieve specific objectives. Automation might not be required at all if human operators are able to match machine capabilities. Strategies in comparing human and machine capabilities and limitations have ignored some human issues (Boyd, 1985). This is particularly acute where preferred levels of automations are concerned. Evaluation of human-machine mismatches should serve as a platform to achieve a better match between operator and machines.

It is thus recommended that operators' skill be used as a factor in establishing appropriate levels of automation. Under normal circumstances, skill develops with maturity and understanding of oneself through a readiness and ability in deciding particular preferences. This phenomenon should be exploited to help in making decisions about the level of automation, and indeed whether or not to automate. This is because automation, by definition, is the replacement of human tasks by machine development to match the capability of human operators with high efficiency. Efforts should be aimed at avoiding wholesale automation and instead should be aimed at compatible and optimally-designed man-machine systems.

In this research, determining the level of automation was focussed on particular equipment, i.e. manual centre-lathes, which by virtue of their usefulness, are the most common industrial machine. There are many human operators who have had some training and gained considerable experience working on these machines. Techniques for deriving an appropriate level of automation should ideally commence on a common machine where an acceptable and valid method might be established before embarking on sophisticated or futuristic equipment. For these reasons, the selection of the manual centre-lathe machine is justified for evaluation purposes.

The operation of manual or automated machines normally requires the presence of humans as operators or just as controllers. Therefore, from a human perspective physical (mismatches) and psychological (trust, self-confidence and preferred level of automation) evaluations should be used in determining the appropriate levels of automation. Hence, there is a necessity for further investigation if there is to be suitable compatibility between humans and automation.

The present study showed some entanglement and interaction of causal conditions which was also observed in a study by Gerbert and Kemmler (1986). This indicates that causes of mismatches could both be independent and dependent of one another. Such was the complexity of the problems involving mismatches in manual tasks that a considerable number of variables were considered in the study.

Evidence obtained from the study confirms that machining activities are prone to mismatches. The findings suggest that mismatches represent a major factor in machine design particularly in defining task allocation methods either for manual or automatic machines. Mismatches were obtained from working practices and information collected from operators who used a particular machine. These could be used to supplement the analysis of any formal system with regard to the operator-machine interface. Inconsistencies between actual and intended use could be resolved to allow favourable options of machine designs suitable for operators.

On a well-designed machine, an operator is expected to make a natural sequence of responses when he is fed with an appropriate series of stimuli (Singleton, 1976). There are variations in the stimuli in manual turning operations so that operators may have to make critical decisions before embarking on any actions. Automation may be the answer, but does not provide the solution to every problem. A good blend between manual work and automation is an obvious objective, but micro analysis is needed to establish the separation between manual and automated work.

The findings of this research provide information for a systematic analysis of the boundary between manual work and automation that is particularly beneficial for design purposes. For turning operations on lathes, users' choices are limited to a small region of preferred levels of automation. Subsequently, optimum design could be achieved for other machining operations in manufacturing.

Providing a particular level of automation for systems inevitably involves tradeoffs especially when making decisions about alternatives between many different levels of automation available (Chapanis, 1996). There is considerable vagueness about tradeoffs, and hence the need for critical analysis.

7.5.2. Transfer region between human operator and machines

Bright (1956) suggested 17 levels for mechanisation profiles while Sheridan (1994) suggested a 10 point level of automation. Findings in this thesis suggested that the overall preferred level of automation was between 5.0 and 6.0 on a scale of 1 to 10. The corresponding region of Sheridan's scale is between 5 and 6 and between 8 and 13 on Bright's scale. It should be stressed that correspondence with the scales suggested by Bright and Sheridan should not be taken literally, but rather be used to identify general aspects of automation. For comparison purposes a summary of the three scales is shown in Table 7.1.

A transfer region can be identified within the levels of automation. This is in fact an area which divides the roles of humans and machines. The transfer of functions from the humans to machines and vice versa should take place within this region. A transfer of function occurring outside this region is considered a "trespass" that needs to be avoided. It has been found that humans intervening in the machine functions of automated systems occurs more frequently than previously thought (Hockey and Maule, 1995). In contrast, the intervention by the machine in human functions is unlikely to occur outside this region (machines are controlled by programs). The "trespass" is most inclined to be committed by human components partly because humans have the capability of doing so and partly because machines fail to meet the anticipated responses.

The preferred level of automation lies within this area and thus the criticality of the region in the context of manufacturing. The transfer region is shown in Figure 7.1. It is concluded that a transfer region inevitably exists between human and machine functions. With respect to turning operations, and with reference to Sheridan's scale of degrees of automation and Bright's mechanisation profiles, it could be deduced from this study that operators (skilled and unskilled) prefer the options as shown in Figures 7.2 and 7.3.

7.6. Comparison with Previous Studies

Hockey and Maule (1995) found that unscheduled manual interventions (UMIs) occurred much more frequently than previously thought which suggests that UMIs

Mechanisation Profile (Bright,1956)	Scale of Degrees of Automation (Sheridan, 1994)	Levels of Automation (Abdul Rani, 1997)	
1. Hand	1. Computer offers no assistance human must do it all	1 (Low)	
2. Hand tool	2. Computer offers alternative actions	2	
3. Powered hand tool	3. Computer offers alternative actions narrows selection to a few	3	
4. Power tool, hand control	4. Computer offers alternative actions suggests one	4	
5. Power tool, fixed cycle, (single function)	5. Computer offers alternative actions suggests one and execute if approve	5	Evidence
6. Power tool (program control)	6. Computer offers alternative actions suggests one, allows time for human to veto before execute	6	from study
7. Power tool systems (remote control)	7. Computer offers alternative actions suggests one, executes automatically, inform human	7	
8. Actuated by introduction of work piece or material	8. Computer offers alternative actions suggests one, executes automatically, informs if human asks	8	
9. Measures characteristic of work	9. Computer offers alternative actions suggests one, execute automatically, informs human if computer decides	9	
10.Signals pre-selected values of measurements (includes error detection)	10.Computer decides everything and acts automatically, ignores human	10 (High)	
11.Records performance			
12.Changes speed, position, direction according to measurement signals			
13.Segregates or rejects according to measurement			
14.Identifies and selects appropriate set of actions			
15.Corrects performance after operating			
16.Corrects performance while operating			
17.Anticipates action required and adjusts to provide it			

Table 7.1 A summary between the Scales of Degrees of Automation, Mechanisation Profiles and the Levels of Automation

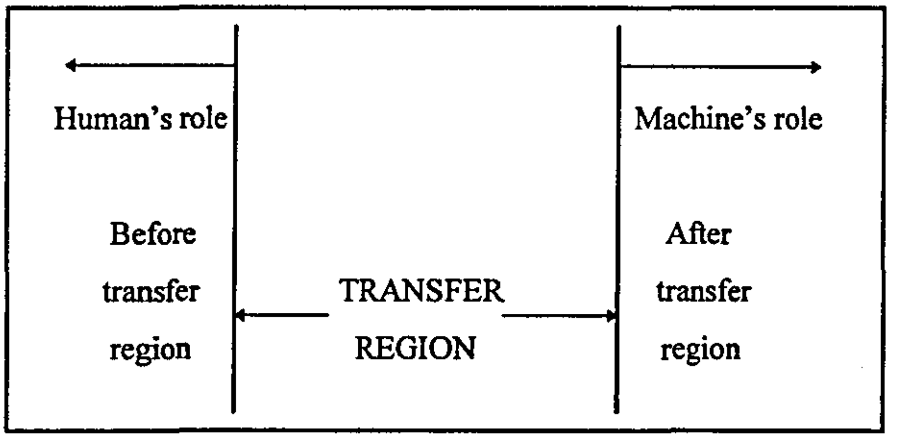


Figure 7.1 The transfer region showing the roles of humans and machines in job execution

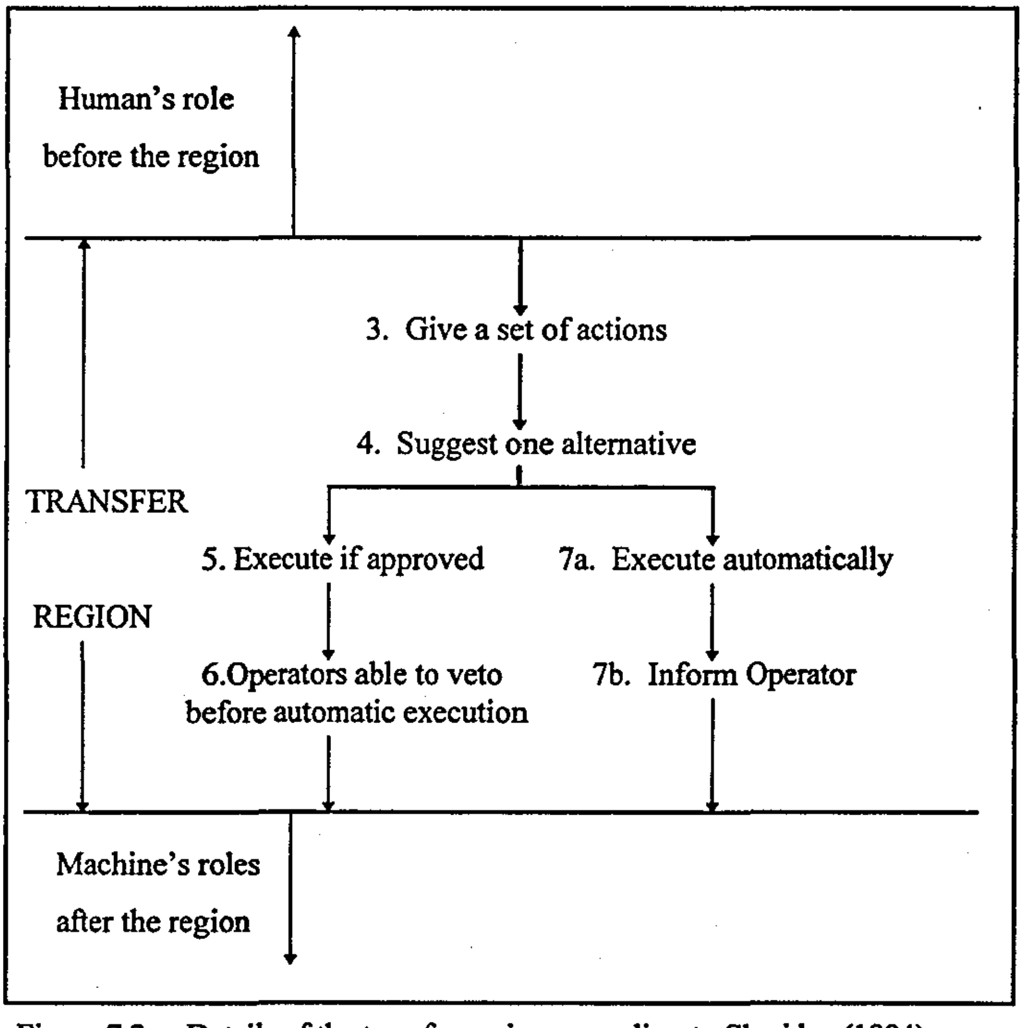


Figure 7.2 Details of the transfer region according to Sheridan (1994).

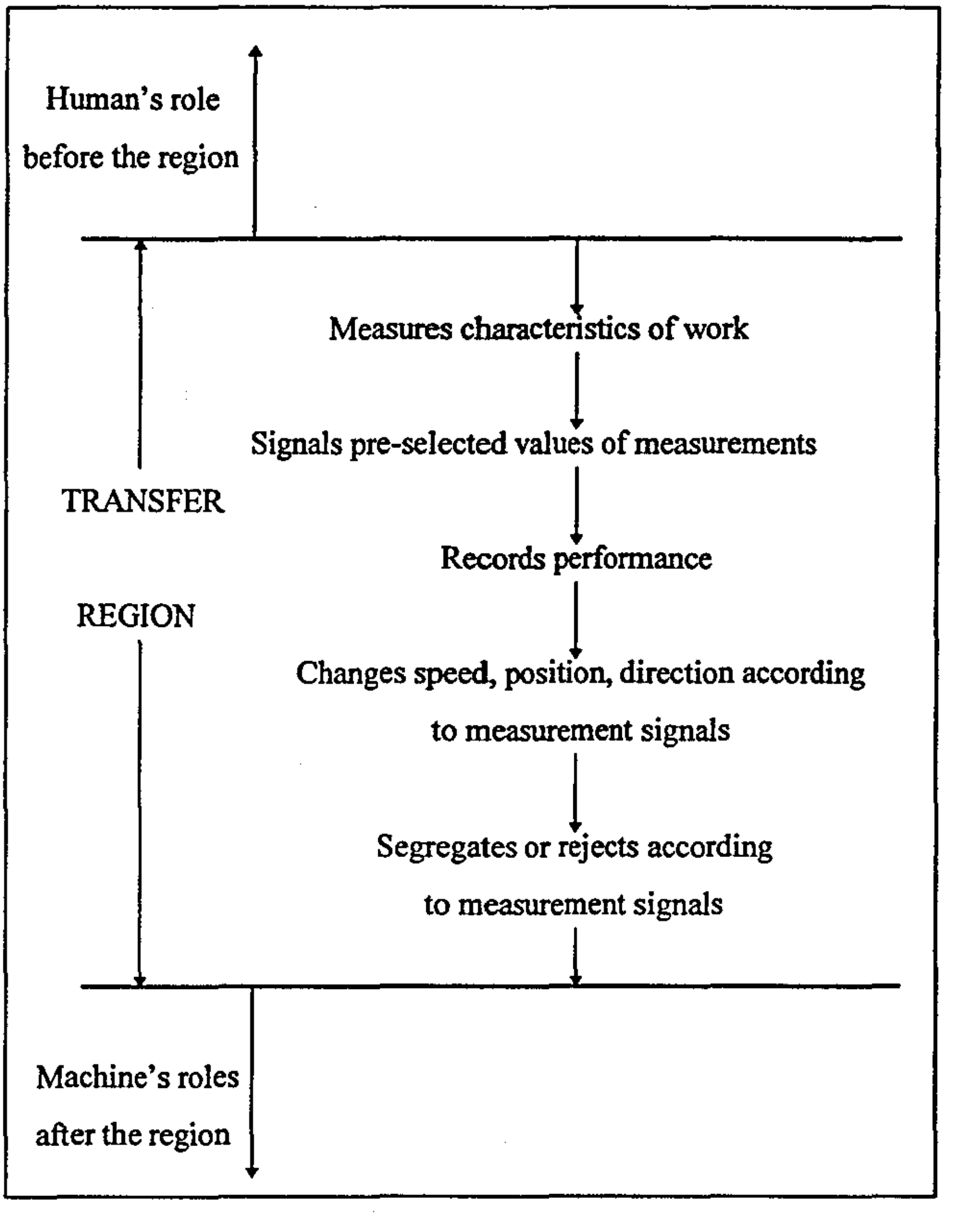


Figure 7.3. Details of the transfer region according to Bright (1956).

play a significant role in day-to-day operator behaviour. The research resulted in similar findings with mismatches frequently occurring as observed from the questionnaire analysis and the field-based simulated experiments in the current study.

From the field-based simulated experiments, the mismatch, "assistance is sometimes required", occurs frequently among both skilled and unskilled operators. It is also shown that the most commonly occurring mismatch is "a procedure or step is repeated several times" for skilled operators and "assistance is sometimes required" for the unskilled operators.

Machine design and training may contribute to the above phenomena. The present design of manual centre-lathes might be causing the problems more or less directly and encouraging mismatches between the human actions and operational tasks in machining. This should be incorporated in future machine design particularly on manual or automated centre-lathe machines and in training procedures in order to achieve mismatch-free operation by both skilled and unskilled operators.

7.7. Generalisation

Generalisations about mismatches, awareness of their occurrence and preferences for automation are not readily validated because of the highly variable nature of humans. Evidence needs to be collected from the past and present to allow confident predictions for the betterment of machining processes when humans are involved. As far as mismatches are concerned, there are hardly any data or information readily obtainable from past records.

Levels of automation may increase but this implies that new skills and competencies are essential as knowledge and skill in physical work processes would be largely replaced by cognitive skills (Rasmussen, 1994). Mismatches were found not to be confined to specific operations but could occur in all operations involving humans and systems in physical work processes. Therefore, understanding of mismatches in manual work operations may provide the basis of solving a specific dimension (i.e. inefficiencies) of human-system problems in automated systems.

The objective of determining an exact level of preference either for total automation, a combination of manual/automation or total manual operation could possibly be achieved using techniques comparable to those of this study. Further more, the preferred levels of automation for specific human tasks such as selection, set-up and inspection have been determined. Subsequently, an overall preference for automation in any particular industry could be obtained.

The study has established that there are no relationships between preferred levels of automation and the identified human characteristics i.e. skill, self-confidence, trust, work experience and age. Therefore, automation should not be based on unfavourable notions about these variables and human weaknesses.

Ergonomically, information on mismatches occurring among groups of machine operators should be useful as a basis on which to suppress them in order to achieve a positive working environment. An understanding of the causes of mismatches identified in the study are essential to identify users, particularly those prone to specific misamatches, and in providing relevant training. Design of equipment with a more complete ergonomics consideration would also contribute to the resolution of the problems.

7.8. Conclusion

That mismatches occur in turning operations using centre-lathe machines is evident from the results of the questionnaire surveys before and after the FBS experiments and from the field-based simulated experiments. Mismatches common to turning operators are also identifiable from the study.

In the light of the current study, there is evidence that skilled and unskilled operators do not prefer total automation (in contrast to the common and informal belief). The relationships between variables reinforce suggestions that humans, machines and tasks contribute to human-machine symbiosis.

CHAPTER 8

SUMMARY AND FURTHER WORK

8.1. Introduction

The discussion and conclusions in the previous chapters showed a positive inclination towards the research expectations. In this chapter, the thesis is summarised, the research contribution is assessed and some recommendations made for further research.

8.2. Summary

The main objective of this study was to obtain an understanding of some of the ergonomics issues in machining within the broad context of manufacturing. Emphasis was placed on human mismatches, relationships between typical basic human characteristics and the critical, but rather indistinct, interface between manual and automated operations.

The literature survey provided ample evidence that supported the need for such an investigation, and a methodology was developed as a vehicle to provide qualitative and quantitative information to explain the phenomena through the collection of data to test hypotheses for a number of related predictions.

Considering the sample population of both skilled and unskilled operators taken as a single group, significant relationships were established between :

i) mismatches and skill, self-confidence, trust, work experience and age;
ii) self-confidence and skill, trust, work experience and age;
iii) trust and skill; and
iv) the preferred levels of automation and mismatches.

However, the study showed that there were no significant relationships between :

i) trust and work experience and age; and
ii) the preferred levels of automation and skill, self-confidence, trust, work experience and age.

From another perspective, the skilled operators showed significant relationships between self-confidence and trust, but the absence of statistically significant relationships between :

i) mismatches and skill, self-confidence, trust, work experience and age;
ii) self-confidence and skill, work experience and age;
iii) trust and skill, work experience and age;
iv) the preferred levels of automation and mismatches, skill, self-confidence, trust, work experience and age.

Contrasting views were expressed by the two groups of skilled and unskilled operators. Subjectively evaluated operator preferences for levels of automation have been determined by questionnaire but it was not possible to establish formal relationships between the preferred levels of automation and skill, self-confidence, trust, work experience and age. Generally there is a need for further study in the area and this is crucial if improved allocation of function is to make a major impact in the manufacturing environment.

8.3. Research Contributions

The Human Task Mismatch Matching method was devised and implemented as a novel tool to be used in a variety of situations where both objective and subjective data is required. The method utilised the matchings between mismatches and tasks involved in machining operations and was found to be applicable to both the experimental and the survey techniques. Although this method was used specifically for turning operations on manual centre lathes, the method is considered to be sufficiently generic and flexible to be applied in other situations involving humans and machines.

This study has also provided an avenue for deeper understanding, of relationships between mismatches and human characteristics and this provides another dimension to the broad body of research in human-machine interfaces. Relationships between relevant human characteristics intrinsic to human behaviour have been established and help in providing a view of human variability that is essential for future machine design and training procedures.

In the context of machining, the human operator and the machine are inseparable and bond together to form a total system. However, the relationships between the two components of the system (human and machine) are complex due to their very different natures. Since humans are the unpredictable component, objective analysis must be supplemented by subjective evaluations, in order to establish the relationships.

The primary focus of the study is on the relationships of mismatches with subjective human characteristics and is considered a major research contribution in the context of these investigations. This is due to the fact that mismatches are inappropriate, unsuitable, inconsistent or uncompatible events that should be corrected as otherwise they become errors which are unproductive events in machining operations. The relationships established between physical (mismatches) and psychological (skill, self-confidence, trust, work experience, age and preferred level of automation) contribute to the current knowledge of the human-machine interface in the context of design and development of human centred-machines.

Psychological considerations are being translated into databases for the development of machines in an effort to improve human-machine interfaces and training for skilled machinists. Understanding differences between the skilled and unskilled operators is an important result of the current study. Unskilled operators may be viewed as mismatches-carrying agents while skilled operators, as a mismatches-free agents. Improving the rate of mismatches in the former and maintaining it in the latter could become the challenge of tomorrow within the context of machining operations. Generally, the primary aims would be to achieve compatible machining tasks and machine designs, and to reduce the training periods before unskilled operators reach acceptable skill levels.

With respect to manual turning operations the types of potential mismatches have been identified and formally categorised by the author (Table 4.1). The categorisation allowed the identification of mismatches inherent in interactions between humans and machines in the performance of machining tasks. Empirical findings suggest that repetition is the most common mismatch committed by skilled operators. The problems of mismatches initially considered generic are translated into specific and well-defined problems so that measures may be considered to reduce or eliminate the mismatches.

An insight into the preferred levels of automation (from operators' perspectives) and the identification of the transfer region between automated and manual operations are also important research contributions. Levels of automation are commonly quoted but in this thesis no attempt has been made to define each level of automation because such a step is considered premature. Rather, attempts have been made to establish the relationships between the preferred levels of automation and variables inherent to humans - research that has not been attempted in previous studies. The formal establishment of those human characteristics that have no relationship to the preferred levels of automation reduces the number of possible variables to be considered by any future research in the field. It is considered that this determination of underlying relationships is the most logical initial step in establishing an overall method of determining suitable levels of automation.

This research reinforces and extends existing knowledge in the specific area of human-machine interfaces as an important strand of human-centred systems philosophy for human-machine symbiosis. It strengthens the applicability of task analysis in the identified situation pursued in this study.

The concepts of task analysis and task allocation of function have long been considered and prove applicable as long as humans and machines exist together at work. The study demonstrated how the procedure in the research was systematically and successfully executed based on this concept.

Practical experience in the measurement and analysis of the subjective views of operators has been gained and this is believed to be appropriate for other similar human-machine scenarios. The problems inherent in the study showed that hands-on experience was important in grasping the experimental design philosophy, particularly in data capture.

While numerous standard statistical techniques are available, appropriate techniques and tests have been identified and used with consideration of the nature of data which are stochastic or non-deterministic. The experimental designs produced experimental results through the FBS experiments and pre-experimental and post-experimental results through the questionnaire survey. In meeting the objectives in the study, data were analysed using Wilcoxon matched-pairs signed-ranks test to establish differences between the results, chi-square tests to establish differences between variables, categories or samples, Mann-Whitney U tests to establish relationships between variables and Spearman correlation coefficients to determine the nature of the relationships between variables. In a sense, the research contribution should be considered in terms of the generation of solution as a whole, results arising from the combination of the research objectives, experimental design, the data capture, the identified statistical techniques and the methods of analysis.

8.4 Further Research

In contrast to a deterministic model, the area studied requires a stochastic modelling approach because random effects play a central role in problem investigation. A random variable (i.e. mismatches) might prevail which is unpredictable in advance. The variable may produce a pattern of randomness that could be represented by a mathematical model (Edwards and Hamson, 1989). Poisson probability distributions could be used to provide an approximation of the variables observed in nature such as the number of deaths and accidents in manufacturing plants (Mendelhall, 1987). In a similar way, the number of mismatches in a particular machining operation could be approximated by the use of probabilistic distributions.

There is evidence that the application of the Human Task Mismatch Matching Method (HTMM) was appropriate to the study of the human characteristics identified in the current study. Other psychological human characteristics such as motivation, boredom and fatigue and the type of tasks could also be studied in order to establish their relationships for the systematic evaluation of training and job requirements. It may also be possible to extend the method's scope of application to cover other more general organisational aspects of the work environment such as shift patterns, pay and sociological conditions.

Informal findings suggest that some tasks are carried out irrespective of human psychological conditions such that detrimental effects develop (e.g. demotivation, boredom, fatigue, and etc.). Elements of tasks may be identified subjectively to match these severe psychological and sociological conditions. A modified version of the HTMM method could be used in such investigations. Subsequently improvements to the task elements could be made in an effort to remove or reduce the negative aspects.

The Human Task-Mismatch Matching (HTMM) method developed in this research could be refined to cover all detailed elements inherent to particular tasks and could be applied to machining operations other than turning. Relationships between variables could be investigated to cover a broad spectrum of tasks and manufacturing activities. Thus a modified HTMM technique could be applied to other machining processes such as milling, grinding and other manufacturing processes such as casting, forming, etc.

Even though there are some differences between human tasks in turning operations and those for other machining operations (e.g. milling and drilling), the HTMM method could be modified and used to identify mismatches for whatever tasks were under investigation.

There is no limitation to the scope of application of the method to other manufacturing activities such as assembly and inspection, and other types of manufacturing organisation such as line or cellular production and continuous processes. Outside the manufacturing sector, such as in the service industry, its scope is clearly visible as the human as an important factor that needs to be considered.

Refinement in terms of increasing the scope of application to other human characteristics and manufacturing processes might be greatly enhanced by computer assistance. The larger amounts of data that could be captured and analysed by computer methods would be most useful in generalisation of the method and results.

An important issue for further work is determining to what extent automation could possibly provide a definable line for the allocation of human functions in machining. A parallel experiment using skilled and unskilled operators on automated machinery would be required.

Preferred levels of automation may be quantified using more sophisticated techniques where further refinement is possible on identified machining or manufacturing processes. The appropriate level of automation compatible with capital and maintenance costs applicable in a wider spectrum of manufacturing organisations and human preferences needs to be considered. Integration of these human and machine perpectives should produce the most effective solution.

From the study, it was established that users do not prefer total automation as some might presume. The current findings agree with Sinaiko (1972) who concluded that mixed automation would be more beneficial than either fully manual or fully automated systems. However, further validation may be necessary to confirm this conclusion. As far as this research is concerned, the findings suggest that over-automation should be avoided and this leads to serious implications for machine design. Proper design related to an appropriate level of automation should prevail in order to avoid incompatibilities, but further investigation in this direction is clearly necessary.

It has been argued that "automation per se is not the key issue" (Norman, 1990). Similarly, automation per se does not survive, but is in need of interaction with humans to achieve particular objectives. An understanding of the implications of different levels of automation should prove useful in establishing a level that is compatible in terms of the interactions from psycho-physical perspectives.

It has also been argued that "the problem with automation was not automation, but the lack of feedback" (Norman, 1990). On this basis, attempts were made to establish the level of automation for three typical human functions in turning operations. The aim was primarily to establish the preferred levels of automation appropriate for specific designs and functions of machines. It is believed that this information is particularly useful to machine designers in refining the design of automated systems. In turn, appropriate feedback design facilities as suggested by Norman (1990) could be introduced. However further work is required to formally establish that this is indeed a viable approach.

Bearing in mind that "automation leads to difficulties" (Norman, 1990), designs of automated systems should consider possible weaknesses during interactions between machines and their users. Extension to the approach undertaken in this research should prove useful in achieving the ultimate design of particular machines.

A mitigation of the cost of performance of activities associate with poor operator-machine interaction could be achieved if appropriate levels of automation are obtained. However, further investigation is essential to pursue these issues.

There is a general need to conduct industrial studies in areas where there are alternatives, and alternative levels of automation are no exception. The HTMM method could be extended and applied as an industrial case study methodology in the absence of other methodologies. This suggests that trade-offs especially between manual and automation remain to be explored.

This study was conducted in the UK using British subjects. Clearly different situations will be found in other parts of the world which are at a different stage of industrial development. In Malaysia, industries have traditionally been labour intensive, but recent developments suggest that mechanisation and automation are becoming increasingly important. Efforts to optimise the mix of labour and mechanisation is an area that would benefit from extensions to this research. Formal training procedures and programmes could be re-evaluated while curricula in tertiary education could be supplemented to cover the broad aspects of manufacturing. Further research potential particularly in machine design and organisation of manufacturing could be realised, perhaps arising out of differences in the cultural and demographic environment when compared to Europe.

A case study would allow the investigation of performance on real and varied machining tasks and thus further confirm the validity of the approach. A nationwide study in industries might reflect the present industrial enviroment that would provide a complete picture of the situation. The research reported here contrived to investigate real machining situations at the operator's workplace, but the tasks carried out were constructed for the purposes of the experiment.

8.5. Conclusion of Research

8.5.1. Conclusions to the research objectives.

The findings suggested some contrasts between the group of skilled and unskilled operators combined and the group of skilled operators. Generally there are differences in the predominate mismatch for skilled (repetitions) and unskilled (require assistance) operators and this knowledge could be useful for design and development of machines and trainings of operators. Machine design and development may focus on compatibilities between machine features and tasks to allow effective operations of machines while training focusses on the possibility of reducing mismatches for unskilled operators while maintaining a very low rate of mismatches for skilled operators.

A discussion of the relationships between variables and the consequences for machine system design and trainings of operators follows.

i) Relationships between mismatches and specific human characteristics.

a) Mismatches and skill.

The design of machine systems should incorporate features appropriate to certain skills and expertise such as the use of job aids compatible to the levels of skill of operators. To cater for the skilled operators, operating procedures and control features ought to be simplified in order to reduce repetition. In training, mismatches committed by the unskilled operators must be identified to allow systematic evaluation and elimination.

b) Mismatches and self-confidence.

A lower frequency of mismatches could be achieved if operators had higher self-confidence. Hence machine designs require features that enhance self-confidence such as feedback mechanisms that would provide information about operator's progress throughout machining. Training should be designed to enhance self-confidence in unskilled operators while refresher training for skilled operators should enable them to maintain self-confidence.

c) Mismatches and level of trust.

Even though operators indicated trust in the capability of automation systems (Lee and Moray, 1994), trust is nevertheless not a trivial characteristic and remains equally important as self-confidence. A feedback mechanism is equally helpful in enhancing trust, and both machine design (compatibility between operators' input and machine responses) and training (compatibility between machines used for training and the actual machines used in industry) are needed to enhance operators' trust of machines. Unskilled operators may suffer from a lack of trust of a machine through being new to the job while skilled operators could suffer from a lack of trust when working on the latest machines.

d) Mismatches and work experience.

Lower mismatches correspond to higher experience of operators and this effect can be enhanced by designing machines to incorporate facilities for training purposes. This could be achieved by installing variable mechanisms on machines used for training at levels suitable for the experience of the operators.

e) Mismatches and age.

Lower mismatches correspond to higher age due to the fact that older operators have greater experience and responsibility. Hence the implications of age on machine design is broadly the same as for experience.

ii) Relationships between self-confidence and specific human characteristics.

a) Self-confidence and skill.

Self-confidence is a characteristic which is associated more with manual controls and the incorporation of such features could enhance self-confidence, particularly for the unskilled operators. Skilled operators show a consistent level of self-confidence so machine design should at least maintain some of the features most familiar to the skilled operators in an effort to maintain their self-confidence.

b) Self-confidence and trust.

Self-confidence influence operators' reliance on manual controls while trust reflects the capabilities of automated systems (Lee and Moray, 1994). Facilities to select the level of automation is an option in machine system design that should be considered. Selection and set-up functions require more automated features because they are a preparatory stage before production when operators may suffer from a lack of self-confidence and might instead prefer to trust an automated system. However, for inspection functions, operators might prefer lower levels of automation because they have lower trust in the machine to provide appropriate decisions.

c) Self-confidence and working experience.

Self-confidence is dependent upon working experience where self-confidence influences operators' reliance on manual control. A machine system design should have variable manual-automation features to cater for the whole spectrum of workers population comprised of skilled and unskilled categories. The varying manual-automation features may be necessary especially for training purposes considering that a fresh operator lacking in experience and self-confidence could build-up his self-confidence and experience progressively with time. Machine system design with fully-automated features may not provide him participation and involvement with his tasks or jobs which could degrade his motivation and attitude.

d) Self-confidence and age.

Self-confidence is dependent upon age when considering the whole population (skilled and unskilled operators) but it is not age-related for skilled operators. Age is synonymous with maturity and thus older operators possess more self-confidence compared with younger operators. Since self-confidence influences operators' reliance on manual controls the older operator would prefer lower automation and have an inclination towards manual control.

iii) Relationships between level of trust and basic human characteristics.

a) Trust and skill.

Even though there is an absence of relationship between trust and skill for skilled operators, a relationship is established between the two variables for the skilled and unskilled operators combined. The relationship could influence machine system design through the adoption of higher levels of automation where trust reflects the capabilities of automated systems (Lee and Moray, 1994).

b) Trust and work experience and age.

Although high trust gives the possibility of high levels of automation, the operators' experience and age have no influence upon trust. Hence, in this respect, elaborate designs (feedback mechanisms, signals for operations and measurement) are of limited use and may simply increase manufacturing costs.

iv) Relationships between the preferred levels of automation and mismatches, skill, self-confidence, level of trust, work experience and age.

Considering the whole group of skilled and unskilled operators, a relationship is established between the preferred levels of automation and mismatches but there is an absence of relationships between mismatches and skill, self-confidence, level of trust, work experience and age. There is evidence that lower mismatches correspond to higher levels of automation.

However, specifically for skilled operators, no relationship is established between the preferred levels of automation and the identified human characteristics (mismatches, skill, self-confidence, level of trust, work experience and age).

For machine system designs, the level of automation is an important parameter which leads to decisions on the selection of machine interfaces (displays i.e. signals and measurements; controls i.e. switches, levers or buttons) and operations (or processes) (facing, drilling, boring, taper turning, and etc.). The absence of relationship indicates that the preferred level of automation is independent of the identified parameters in the investigation. Hence, the level of automation may be determined and established irrespective of those parameters. Other parameters (beyond the scope of this study) may influence the determination of a particular level of automation.

Generally, it is anticipated that skills develop with the levels of automation in machine system design which provides the explanation for the absence of relationship between the variables. It has been suggested by Lee and Moray (1994) that self-confidence is associated more towards manual control while trust is significant in automated system. Although findings suggest that the variables have no influence in selecting the levels of automation, a compromise between manual and automation remains the best option in machine sytem design. Work experience and age are not associated to the preferred levels of automation.

Shortcomings may be compensated by having appropriate training and increased exposure. Furthermore, there is no major concern in discriminating between young and old operators in designing and selecting the appropriate levels of automation.

v) The preferred levels of automation

With respect to turning operations, an appropriate mix between manual and automatic operation is preferred by operators as expressed by values of PLA of 7.0 for the overall functions, 6.0 for the selection and set-up functions and 5.0 for the inspection functions.

8.6. Conclusion

The current study has provided several answers to particular questions with respect to human-machine interactions. Beside the empirical results, the study has established a research methodology and highlighted further research essential for prospective researchers in the area. On the whole, the research has come to a positive and very encouraging conclusion. Finally, it is expected that the "war of words" between the human and machine components (eg. Wiener and Curry (1980), Norman (1993)) will recede and the gap narrowed to expose a definitive boundary between them.

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APPENDIX A

Task elements (in questionnaires) are grouped into selection, set-up and inspection functions.

TASK ELEMENTS	Selection (SEL)	Set-up (SET)	Inspection (INSP)
1. First time correct selection of a tool or tools for a particular operation.	SEL		
2. First time correct setting up of tools to centre height for a particular operation		SET	
3. Selection of correct work holding method for a particular set-up.	SEL		
4. Checking diameter of stock material before cutting begins.			INSP
5. Selection of correct speed for a particular workpiece and process.	SEL		
6. Setting of cutting speed for a particular wprkpiece and process		SET	
7. Selection of feed for particular workpiece or process.	SEL		
8. Setting of cutting feed for particular workpiece or process.		SET	
9. First time correct positioning of tool datum to zero dial for a particular operation		SET	
10. Setting depth of cut for a particular operation		SET	
11. Engaging clutch for a particular cutting operation		SET	
12. Selection of direction of travel for a particular cutting operation	SEL		
13. Engaging feed for a particular cutting operation.		SET	
14. Checking required length of cut on a workpiece			INSP
15. Checking required diameter on a workpiece			INSP
16. Selection of the tool holding position on a toolpost	SEL		
17. Manual feeding of drills (eg. a drill or a hammer)		SET	
18. Selection of speeds for various sizes of drills or reamers.	SEL		
19. Selection of a sleeve for a reamer.	SEL		
20. Selection of a feed for taper cutting.	SEL		
21. Manual feeding for taper cutting		SET	
22. Checking depth of bore			INSP
23. Checking internal diameter of a bore			INSP
24. Positioning toolpost to a required angle (eg. chamfering)	SEL		

APPENDIX B

Instruction to subjects before performing machining operation to produce a sample component.

1. Please observe the safety rules both in the workshop and on the machine. Overalls, proper shoes and goggles should be worn where appropriate.

2. This experiment involves simple turning operations on a manual centre lathe, yet accidents could possibly happen in unexpected circumstances. Therefore as an operator, preventive measures need to take to avoid any accidents.

3. Please ask for assistance whenever you have problems with machining because a laboratory technician is readily available to help you. This includes tool identification, machine operations, etc.

4. Please continue machining at your own normal pace because time limits are not imposed on you i.e. you are not under pressure to complete the job on time.

5. Please ignore the presence of the experimenter although he may interrupt you at work by asking some simple questions. The presence of an experimenter should not in any way disturb you at work.

6. You are allowed to get assistance in any way during machining as long as you are able to proceed machining safely and smoothly.

7. A drawing (MRAR/001) of a sample component for you to manufacture is provided.

APPENDIX C

Observation sheet for mismatches during field-based simulated experiments in turning operations on a manual centre-lathe.

Particular	Details
Subject (no.)	
Age	
Skill category	Skilled / Unskilled
Date of experiment	
Place of experiment	

Selection	Set-up	Inspection	Task Elements	Intrusion	Omission	Commission	Reversal in sequence	Wrong request	Repetition	Acts on wrong component	Mis-application	Violations	Other
			SETTING UP FOR CUTTING										
1			1. Select insert, tool and assembly										
	1		2. Fix in revolving centre										
	1		3. Set tool to centre height										
	1		4. Hold the wk/piece										
		1	5. Check diameter of wk/piece										
1			6. "On" motor to start machine										
1			7. Select speed										
	1		8. Determine feed										
			FACING OFF										
	1		9. Saddle to approach wk/piece										
	1		10. Set tool datum to wk/piece										
	1		11. Set depth of cut										
	1		12. Engage clutch										
	1		13. Engage direction of travel										
	1		14. Engage feed										
	1		15. Facing off										
	1		16. Disengage										
			TURNING FOR mm and mm dia.										
	1		17. Saddle to approach job										

	1		18. Set tool datum to zero										
	1		19. Set depth of cut										
	1		20. Engage clutch										
	1		21. Engage direction of travel										
	1		22. Engage feed										
		1	23. Check length of specimen										
	1		24. Manual cutting										
		1	25. Check diameter before finish cut i.e. mm and diameter										
	1		26. Disengage										
1			27. Select a drill										
1			28. Select a chuck										
1			29. Select spindle speed										
	1		30. Determine feed										
	1		31. Fit chuck on tailstock										
	1		32. Lock tailstock in position										
	1		33. Engage clutch										
	1		34. Manual feed of drill										
			DRILL THROUGH										
1			35. Select a drill										
1			36. Select a chuck										
	1		37. Select spindle feed										
	1		38. Lock tailstock in position										
1			39. Select speed										
	1		40. Engage clutch										
	1		41. Manual feed of drill										
	1		42. Remove drill and chuck										
			REAMING										
1			43. Select a reamer										
1			44. Select a sleeve for the reamer										
	1		45. Fit sleeve in tailstock										
	1		46. Lock tailstock in position										
1			47. Select speed										
	1		48. Engage clutch										
	1		49. Manual feed of reamer										
	1		50. Remove reamer and sleeve										
			MAKING A GROOVE										
1			51. Select insert, tool and assembly										
	1		52. Set tool to centre-height										
1			53. Select speed										
	1		54. Determine feed										
	1		55. Saddle to approach job										
	1		56. Engage length of cut										
	1		57. Engage clutch										
	1		58. Engage direction of travel										
	1		59. Engage feed to form feed										
	1		60. Disengage feed										
	1		61 Clear saddle from workpiece										

			TAPER TURNING (10 degrees taper)										
1			62. Select tool										
	1		63. Set tool to centre-height										
	1		64. Adjust tool-post to angle										
1			65. Select speed										
	1		66. Determine feed										
	1		67. Engage clutch										
	1		68. Manual feed to cut a taper										
	1		69. Disengage										
	1		70. Clear saddle from wk/piece										
			FACING OFF										
	1		71. Hold the workpiece										
1			72. Select tool										
	1		73. Set tool on tool post										
	1		74. Set tool to centre-heights										
		1	75. Check length of wk/piece										
	1		76. Set tool datum to zero dial										
	1		77. Set depth of cut										
	1		78. Engage clutch										
	1		79. Engage direction of travel										
	1		80. Engage feed										
	1		81. Facing off										
	1		82. Check length of workpiece										
	1		83. Disengage										
	1		84. Clear saddle from workpiece										
			DRILL BEFORE BORING										
1			85. Select drill										
1			86. Select chuck										
	1		87. Fit chuck in tailstock										
	1		88. Lock tailstock in position										
1			89. Select speed										
	1		90. Engage clutch										
	1		91. Manual feed of drill										
	1		92. Remove drill and chuck										
			BORING										
1			93. Select insert, tool and assembly										
	1		94. Set tool to centre height										
1			95. Select speed										
	1		96. Determine feed										
	1		97. Determine depth of cut										
	1		98. Saddle to approach job.										
	1		99. Engage clutch										
	1		100. Engage direction of travel										
	1		101. Engage feed										
	1		102. Cutting action (boring)										

		1	103. Check depth of bore										
		1	104. Check diameter of bore										
	1		105. Repeat cutting (boring)										
	1		106. Disengage										
	1		107. Clear saddle from workpiece										
			CHAMFER										
1			108. Select tool for chamfer										
	1		109. Position toolpost to 45 degrees										
1			110. Select speed										
	1		111. Chamfer cut (manually)										
	1		112. Clear saddle from workpiece										
	1		113. Remove workpiece										

APPENDIX D

DEPARTMENT OF MANUFACTURING ENGINEERING
LOUGHBOROUGH UNIVERSITY

A QUESTIONNAIRE

SURVEY

YOUR OPINION IS ESSENTIAL
IN UNDERSTANDING ISSUES OF
HUMAN PERFORMANCE IN MANUAL
TURNING OPERATIONS

A standard set of opinions are prepared and stay the same for all the tasks identified in this questionnaire. However, for any other opinions not found in the list, feel free to put them down in the space provided. All information given in the questionnaires shall be dealt with in strict confidence.

Thank you.
M.R.Abdul Rani
Research Student

A. <u>A survey on mismatches that could occur to operators during turning operations on manual centre lathes</u>

Which of the following mismatches are most common in machining for the tasks indicated. (Please answer all by placing a tick ☐ in the appropriate choice box or boxes. You can tick more than one choice where appropriate).

Leave this space blank

1. First time correct selection of a tool or tools for a particular operation.

	Assistance is sometimes required
	An important step in the procedure is left out
	A step is performed incorrectly
	A series of steps need to repeat due to memory lapse
	A mistake or error in a request for a certain item
	A procedure or step is repeated several times
	Wrong usage of a component, a tool or an instrument
	Wrong method is applied in a task
	A step does not comply to procedures or guidelines
	Execute correct and perfect procedure always
	Non-specific mismatches, please indicate below :

2. First time correct setting up of tools to centre height for a particular operation

	Assistance is sometimes required
	An important step in the procedure is left out
	A step is performed incorrectly
	A series of steps need to repeat due to memory lapse
	A mistake or error in a request for a certain item
	A procedure or step is repeated several times
	Wrong usage of a component, a tool or an instrument
	Wrong method is applied in a task
	A step does not comply to procedures or guidelines
	Execute correct and perfect procedure always
	Non-specific mismatches, please indicate below :

3. Selection of correct work holding method for a particular set-up.

	Assistance is sometimes required
	An important step in the procedure is left out
	A step is performed incorrectly
	A series of steps need to repeat due to memory lapse
	A mistake or error in a request for a certain item
	A procedure or step is repeated several times
	Wrong usage of a component, a tool or an instrument
	Wrong method is applied in a task
	A step does not comply to procedures or guidelines
	Execute correct and perfect procedure always
	Non-specific mismatches, please indicate below :

4. Checking diameter of stock material before cutting begins.

	Assistance is sometimes required
	An important step in the procedure is left out
	A step is performed incorrectly
	A series of steps need to repeat due to memory lapse
	A mistake or error in a request for a certain item
	A procedure or step is repeated several times
	Wrong usage of a component, a tool or an instrument
	Wrong method is applied in a task
	A step does not comply to procedures or guidelines
	Execute correct and perfect procedure always
	Non-specific mismatches, please indicate below :

5. Selection of correct speed for a particular workpiece and process.

	Assistance is sometimes required
	An important step in the procedure is left out
	A step is performed incorrectly
	A series of steps need to repeat due to memory lapse
	A mistake or error in a request for a certain item
	A procedure or step is repeated several times
	Wrong usage of a component, a tool or an instrument
	Wrong method is applied in a task
	A step does not comply to procedures or guidelines
	Execute correct and perfect procedure always
	Non-specific mismatches, please indicate below :

6. Setting of cutting speed for a particular workpiece and process.

	Assistance is sometimes required
	An important step in the procedure is left out
	A step is performed incorrectly
	A series of steps need to repeat due to memory lapse
	A mistake or error in a request for a certain item
	A procedure or step is repeated several times
	Wrong usage of a component, a tool or an instrument
	Wrong method is applied in a task
	A step does not comply to procedures or guidelines
	Execute correct and perfect procedure always
	Non-specific mismatches, please indicate below :

7. Selection of feed for particular workpiece or process.

	Assistance is sometimes required
	An important step in the procedure is left out
	A step is performed incorrectly
	A series of steps need to repeat due to memory lapse
	A mistake or error in a request for a certain item
	A procedure or step is repeated several times
	Wrong usage of a component, a tool or an instrument
	Wrong method is applied in a task
	A step does not comply to procedures or guidelines
	Execute correct and perfect procedure always
	Non-specific mismatches, please indicate below :

8. Setting of cutting feed for particular workpiece or process.

	Assistance is sometimes required
	An important step in the procedure is left out
	A step is performed incorrectly
	A series of steps need to repeat due to memory lapse
	A mistake or error in a request for a certain item
	A procedure or step is repeated several times
	Wrong usage of a component, a tool or an instrument
	Wrong method is applied in a task
	A step does not comply to procedures or guidelines
	Execute correct and perfect procedure always
	Non-specific mismatches, please indicate below :

9. First time correct positioning of tool datum to zero dial for a particular operation.

	Assistance is sometimes required
	An important step in the procedure is left out
	A step is performed incorrectly
	A series of steps need to repeat due to memory lapse
	A mistake or error in a request for a certain item
	A procedure or step is repeated several times
	Wrong usage of a component, a tool or an instrument
	Wrong method is applied in a task
	A step does not comply to procedures or guidelines
	Execute correct and perfect procedure always
	Non-specific mismatches, please indicate below :

10. Setting depth of cut for a particular operation

	Assistance is sometimes required
	An important step in the procedure is left out
	A step is performed incorrectly
	A series of steps need to repeat due to memory lapse
	A mistake or error in a request for a certain item
	A procedure or step is repeated several times
	Wrong usage of a component, a tool or an instrument
	Wrong method is applied in a task
	A step does not comply to procedures or guidelines
	Execute correct and perfect procedure always
	Non-specific mismatches, please indicate below :

11. Engaging clutch for a particular cutting operation

	Assistance is sometimes required
	An important step in the procedure is left out
	A step is performed incorrectly
	A series of steps need to repeat due to memory lapse
	A mistake or error in a request for a certain item
	A procedure or step is repeated several times
	Wrong usage of a component, a tool or an instrument
	Wrong method is applied in a task
	A step does not comply to procedures or guidelines
	Execute correct and perfect procedure always
	Non-specific mismatches, please indicate below :

12. Selection of direction of travel for a particular cutting operation

	Assistance is sometimes required
	An important step in the procedure is left out
	A step is performed incorrectly
	A series of steps need to repeat due to memory lapse
	A mistake or error in a request for a certain item
	A procedure or step is repeated several times
	Wrong usage of a component, a tool or an instrument
	Wrong method is applied in a task
	A step does not comply to procedures or guidelines
	Execute correct and perfect procedure always
	Non-specific mismatches, please indicate below :

13. Engaging feed for a particular cutting operation.

	Assistance is sometimes required
	An important step in the procedure is left out
	A step is performed incorrectly
	A series of steps need to repeat due to memory lapse
	A mistake or error in a request for a certain item
	A procedure or step is repeated several times
	Wrong usage of a component, a tool or an instrument
	Wrong method is applied in a task
	A step does not comply to procedures or guidelines
	Execute correct and perfect procedure always
	Non-specific mismatches, please indicate below :

14. Checking required length of cut on a workpiece

	Assistance is sometimes required
	An important step in the procedure is left out
	A step is performed incorrectly
	A series of steps need to repeat due to memory lapse
	A mistake or error in a request for a certain item
	A procedure or step is repeated several times
	Wrong usage of a component, a tool or an instrument
	Wrong method is applied in a task
	A step does not comply to procedures or guidelines
	Execute correct and perfect procedure always
	Non-specific mismatches, please indicate below :

15. Checking required diameter on a workpiece

	Assistance is sometimes required
	An important step in the procedure is left out
	A step is performed incorrectly
	A series of steps need to repeat due to memory lapse
	A mistake or error in a request for a certain item
	A procedure or step is repeated several times
	Wrong usage of a component, a tool or an instrument
	Wrong method is applied in a task
	A step does not comply to procedures or guidelines
	Execute correct and perfect procedure always
	Non-specific mismatches, please indicate below :

16. Selection of the tool holding position on a toolpost

	Assistance is sometimes required
	An important step in the procedure is left out
	A step is performed incorrectly
	A series of steps need to repeat due to memory lapse
	A mistake or error in a request for a certain item
	A procedure or step is repeated several times
	Wrong usage of a component, a tool or an instrument
	Wrong method is applied in a task
	A step does not comply to procedures or guidelines
	Execute correct and perfect procedure always
	Non-specific mismatches, please indicate below :

17. Manual feedding of drills (eg. a drill or a hammer)

	Assistance is sometimes required
	An important step in the procedure is left out
	A step is performed incorrectly
	A series of steps need to repeat due to memory lapse
	A mistake or error in a request for a certain item
	A procedure or step is repeated several times
	Wrong usage of a component, a tool or an instrument
	Wrong method is applied in a task
	A step does not comply to procedures or guidelines
	Execute correct and perfect procedure always
	Non-specific mismatches, please indicate below :

18. Selection of speeds for various sizes of drills or reamers.

	Assistance is sometimes required
	An important step in the procedure is left out
	A step is performed incorrectly
	A series of steps need to repeat due to memory lapse
	A mistake or error in a request for a certain item
	A procedure or step is repeated several times
	Wrong usage of a component, a tool or an instrument
	Wrong method is applied in a task
	A step does not comply to procedures or guidelines
	Execute correct and perfect procedure always
	Non-specific mismatches, please indicate below :

19. Selection of a sleeve for a reamer.

	Assistance is sometimes required
	An important step in the procedure is left out
	A step is performed incorrectly
	A series of steps need to repeat due to memory lapse
	A mistake or error in a request for a certain item
	A procedure or step is repeated several times
	Wrong usage of a component, a tool or an instrument
	Wrong method is applied in a task
	A step does not comply to procedures or guidelines
	Execute correct and perfect procedure always
	Non-specific mismatches, please indicate below :

20. Selection of a feed for taper cutting.

	Assistance is sometimes required
	An important step in the procedure is left out
	A step is performed incorrectly
	A series of steps need to repeat due to memory lapse
	A mistake or error in a request for a certain item
	A procedure or step is repeated several times
	Wrong usage of a component, a tool or an instrument
	Wrong method is applied in a task
	A step does not comply to procedures or guidelines
	Execute correct and perfect procedure always
	Non-specific mismatches, please indicate below :

21. Manual feeding for taper cutting

	Assistance is sometimes required
	An important step in the procedure is left out
	A step is performed incorrectly
	A series of steps need to repeat due to memory lapse
	A mistake or error in a request for a certain item
	A procedure or step is repeated several times
	Wrong usage of a component, a tool or an instrument
	Wrong method is applied in a task
	A step does not comply to procedures or guidelines
	Execute correct and perfect procedure always
	Non-specific mismatches, please indicate below :

22. Checking depth of bore

	Assistance is sometimes required
	An important step in the procedure is left out
	A step is performed incorrectly
	A series of steps need to repeat due to memory lapse
	A mistake or error in a request for a certain item
	A procedure or step is repeated several times
	Wrong usage of a component, a tool or an instrument
	Wrong method is applied in a task
	A step does not comply to procedures or guidelines
	Execute correct and perfect procedure always
	Non-specific mismatches, please indicate below :

23. Checking internal diameter of a bore

	Assistance is sometimes required
	An important step in the procedure is left out
	A step is performed incorrectly
	A series of steps need to repeat due to memory lapse
	A mistake or error in a request for a certain item
	A procedure or step is repeated several times
	Wrong usage of a component, a tool or an instrument
	Wrong method is applied in a task
	A step does not comply to procedures or guidelines
	Execute correct and perfect procedure always
	Non-specific mismatches, please indicate below :

24. Positioning toolpost to a required angle (eg. chamfering)

	Assistance is sometimes required
	An important step in the procedure is left out
	A step is performed incorrectly
	A series of steps need to repeat due to memory lapse
	A mistake or error in a request for a certain item
	A procedure or step is repeated several times
	Wrong usage of a component, a tool or an instrument
	Wrong method is applied in a task
	A step does not comply to procedures or guidelines
	Execute correct and perfect procedure always
	Non-specific mismatches, please indicate below :

B. Reasons for the occurrence of mismatches in turning operations.

25. Which are the TWO most common reasons for mismatches among machine operators.

	Some operators are less knowledgable about machining tasks
	Careless mistakes
	Some operators are less well-trained.
	Pressure to complete jobs on time.
	Other reasons, please specify.

C. Effects of mismatches on production.

26. What are the TWO most common effects of mismatches on production in industry.

	Production delays
	Scrap work.
	Loss of materials.
	Loss of precious man-hours.
	Loss of quality in production.
	No apparent effects of mismatches on production.
	Other effects, please specify.

D. Preventing the occurrence of mismatches among machinists.

27. Give TWO best suggestions on how to prevent or reduce the occurrence of mismatches among machine operators.

	Frequent re-training.
	Improvement in machining instruction aids.
	Special monitoring procedures for machining operations eg. statistical process control, etc.
	Mismatches are beyond preventive measures.
	Other suggestions, please specify.

E. Personal details of respondents

28. Give your level of skill in manual machining operations.

	Skilled
	Semi-skilled
	Low/unskilled

29. Give your working experience (in years).

	Less than 5 years
	Between 5 and less than 10 years
	Between 10 and less than 15 years
	Between 15 and less than 20 years
	Between 20 and less than 25 years
	25 years and above

30. Give your present age.

	Less than 20 years.
	Between 20 and less than 25 years.
	Between 25 and less than 30 years.
	Between 30 and less than 35 years.
	Between 35 and less than 40 years.
	Between 40 and less than 45 years.
	Between 45 and less than 50 years.
	Between 50 and less than 55 years.
	55 years and over.

F. Operators' self-assessment of self-confidence, level of trust and preferred levels of automation.

31. Please indicate (circle appropriate number below) your level of self-confidence to execute the tasks (No. 1 - 24 above) using a manual centre lathe.

Very very low ←									Very very high →
1	2	3	4	5	6	7	8	9	10

32. Please indicate (circle appropriate number below) your level of trust to execute the tasks (No. 1 - 24 above) using a manual centre lathe.

Very very low ←									Very very high →
1	2	3	4	5	6	7	8	9	10

33. Please indicate (circle appropriate number below) the overall level of automation that you PREFER to execute the tasks (No. 1 - 24 above) using a manual centre lathe.

Very very low ←									Very very high →
1	2	3	4	5	6	7	8	9	10

33. Please indicate (circle the appropriate number below) the levels of automation that you prefer for the each tasks below (Tasks 1 to 24 of part A above).

Element of task	Levels of automation									
	Fully manual ←									Fully automatic →
a. First time right in selecting tools	1	2	3	4	5	6	7	8	9	10
b. First time right in setting-up tools to c/hts	1	2	3	4	5	6	7	8	9	10
c. Select correct work holding method	1	2	3	4	5	6	7	8	9	10
d. Check diameter of a stock materials	1	2	3	4	5	6	7	8	9	10
e. Select correct speed	1	2	3	4	5	6	7	8	9	10
f. Set cutting speed	1	2	3	4	5	6	7	8	9	10
g. Select feed	1	2	3	4	5	6	7	8	9	10
h. Set cutting feed	1	2	3	4	5	6	7	8	9	10
i First time right to set tool datum to zero	1	2	3	4	5	6	7	8	9	10
j. Set depth of cut	1	2	3	4	5	6	7	8	9	10
k. Engage clutch	1	2	3	4	5	6	7	8	9	10
l. Select direction of travel	1	2	3	4	5	6	7	8	9	10
m. Engaging feed	1	2	3	4	5	6	7	8	9	10
n. Checking required length of a cut	1	2	3	4	5	6	7	8	9	10
p. Checking required diameter on a w/piece	1	2	3	4	5	6	7	8	9	10
q. Select tool holding position	1	2	3	4	5	6	7	8	9	10
r. Feeding tools	1	2	3	4	5	6	7	8	9	10
s. Select speeds for drills or reamers	1	2	3	4	5	6	7	8	9	10
t. Select a sleeve for a reamer	1	2	3	4	5	6	7	8	9	10
u. Select feed for taper cutting	1	2	3	4	5	6	7	8	9	10
v. Checking depth of bore	1	2	3	4	5	6	7	8	9	10
w. Checking internal diameter of bore	1	2	3	4	5	6	7	8	9	10
x. Position toolpost to a required angle	1	2	3	4	5	6	7	8	9	10

Thank you very much for your co-operation

APPENDIX E : RESULTS OF A SAMPLE STUDY

A sample study was carried out observing an operator performing actual manual turning operations on a shop floor. Observation was carried out based on the identifed methodology i.e. the Human Task Mismatch Matching Method.

Selection	Set-up	Inspection	TASK ELEMENTS	Intrusion	Omission	Commission	Reversal in sequence	Wrong request	Repetition	Acts on wrong component	Mis-application	Violations	Other
1			1. Locate a file										1
	1		2. Remove rough surface on thread										
1			3. Select a cutting speed										
	1		4. Set-up work piece										
	1		5. Centre the work piece						1				
	1		6. Tighten chuck										
1			7. Select a cutting speed										
	1		8. Feeding										
		1	9. Check thread on male using female						1				
	1		10. Hold work piece on chuck										
		1	11. Check concentricity										
	1		12. Set zero datum of tool										
	1		13. Screw-cutting (manual)										
	1		14. Undo chuck										
	1		15. Centre the workpiece						1				
	1		16. Tighten the workpiece						1				
	1		17. Saddle to approach job										
	1		18. Stop machine										
	1		19. Feed tools										
		1	20. Check thread										
			21. File away rough surface										
	1		22. Hold the workpiece						1				
	1		23. Centre the work piece									1	
			24. Set-up tool on tool post										
	1		25. Set tool to centre height										
1			26. Select speed										
		1	27. Check length of cut										
		1	28. Check cutting feed	1									

			29. Manual cutting										
	1		30. Set to zero datum										
	1		31. Manual cut of thread										
			32. Check up the thread							1			
			33. Repeat cutting						1				
1			34. Select speed										
1			35. Select a tool										
	1		36. Undo the chuck										
	1		37. Hold the workpiece						1				
	1		38. Centre-work piece										
	1		39. Tighten chuck										
1			40. Select cutting feed										
	1		41. Set the cutting feed										
	1		42. Screw cutting (manual)										
	1		43. Feed in tool										
1			44. Select a tool										
		1	45. Check with the thread							1			
	1		47. Repeat cutting										
		1	48. Repeat checking the thread										
	1		49. Hold the work piece										
	1		50. Centre workpiece						1			1	
1			51. Select cutting speed										
1			52. Select cutting feed										
	1		53. Manual cutting of screw thread										
1			54. Select a tool to check surface										
		1	55. Check the thread										
1			56. Select a tool										
			57. Remove rough edges										
	1		58. Undo chuck and remove wk/piece										
	1		59. Hold the w/piece						1			1	
	1		60. Centre the workpiece										
1			61. Select cutting speed										
1			62. Select cutting feed for screw cut										
	1		63. Screw cutting manually										
1			64. Select speed										
1			65. Select a tool to remove rough surf.										
	1		66. Remove rough surface										
	1		67. Hold the workpiece						1				
	1		68. Centre the wk/piece						1			1	
1			69. Select speed										
	1		70. Saddle to approach wk/piece										
	1		71. Set tool to zero datum										
			72. Screw cutting manually										
	1		73. Undo chuck and remove wk/piece										

Appendix F

F1 : Mismatches in the field-based simulated experiment for skilled operators

Subject	Intrusion	Omission	Commis-sion	Reversal in sequence	Wrong request	Repeti-tion	Acts on wrong compo-nents	Mis-applicati on	Violation	Other mis-matches	Total
1	0	0	0	1	0	14	0	0	0	0	15
2	0	0	0	0	0	6	0	0	1	0	7
3	0	1	0	0	0	4	1	0	1	0	7
4	2	0	0	1	0	12	0	0	1	0	16
5	0	1	0	0	0	2	1	0	1	0	5
6	0	2	0	0	0	5	5	0	1	0	13
7	0	0	1	0	0	7	1	0	0	0	9
8	1	1	0	0	0	6	0	0	0	0	8
9	0	1	0	1	0	15	2	0	1	0	20
10	0	0	0	1	0	10	1	0	2	0	14
11	0	0	0	0	0	5	0	0	0	0	5
12	2	0	2	1	1	13	0	0	0	0	19
13	0	0	0	0	0	5	0	0	0	0	5
14	0	0	0	2	0	3	1	0	0	0	6
15	0	0	0	0	0	4	0	0	0	0	4
16	0	0	1	1	0	1	0	0	0	0	3
Total	5	6	4	8	1	112	12	0	8	0	156

Appendix F

F2 : Mismatches in the field-based simulated experiment for unskilled operators

Subject	Intrusion	Omission	Commis-sion	Reversal in sequence	Wrong request	Repeti-tion	Acts on wrong compo-nents	Mis-applicati on	Violation	Other mis-matches	Total
1	80	1	5	5	0	15	5	7	12	0	130
2	7	5	0	1	0	8	0	0	0	0	21
3	9	3	3	0	0	12	8	2	4	0	41
4	18	6	6	0	0	3	1	0	0	0	34
5	30	0	3	0	0	16	0	0	1	0	50
6	24	0	4	0	2	3	2	2	0	0	37
7	34	0	2	0	0	7	3	0	0	0	46
8	15	4	0	0	0	5	1	0	2	0	27
9	30	1	3	0	0	2	1	0	0	0	37
10	34	3	1	0	0	8	1	1	0	0	48
11	7	1	0	0	0	3	3	0	0	0	14
12	18	3	10	1	1	1	2	1	6	0	43
Total	306	27	37	7	3	83	27	13	25	0	528

Appendix F

F3 : Mismatches for skilled operators from questionnaire survey before the FBS experiment

Subject	Intrusion	Omission	Commis-sion	Reversal in sequence	Wrong request	Repeti-tion	Acts on wrong compo-nents	Mis-applicati on	Violation	Other mis-matches	Total
1	0	0	0	0	0	4	0	0	5	0	9
2	0	0	0	0	0	0	0	0	1	9	10
3	16	0	2	0	0	14	14	6	2	0	54
4	6	0	0	1	0	5	0	1	2	0	15
5	0	0	2	0	1	3	0	5	7	0	18
6	8	0	0	0	0	0	0	0	1	0	9
7	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0
9	0	4	5	2	0	10	3	5	1	0	30
10	5	0	20	3	3	11	10	12	8	0	72
11	0	0	0	0	1	0	0	0	0	0	1
12	0	0	13	5	3	10	11	9	1	0	52
13	0	2	4	13	3	10	0	4	7	0	43
14	7	1	6	4	1	15	5	4	10	1	54
15	0	0	4	0	0	14	0	1	3	0	22
16	0	0	1	1	4	11	0	1	4	3	25
Total	42	7	57	29	16	107	43	48	52	13	414

Appendix F

F4 : Mismatches for skilled operators from questionnaire survey after the FBS experiment.

Subject	Intrusion	Omission	Commis-sion	Reversal in sequence	Wrong request	Repeti-tion	Acts on wrong compo-nents	Mis-applicati on	Violation	Other mis-matches	Total
1	0	0	0	0	0	3	0	0	0	0	3
2	0	0	0	0	0	0	0	0	1	6	7
3	21	0	0	0	0	0	12	17	1	0	51
4	0	0	0	0	0	10	0	0	0	0	10
5	0	0	0	0	0	0	1	3	8	0	12
6	6	0	0	0	0	0	0	0	1	0	7
7	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0
9	0	6	12	2	0	5	4	14	0	0	43
10	0	0	4	0	0	5	3	2	7	0	21
11	0	0	0	0	0	0	0	0	0	0	0
12	1	0	3	6	1	11	4	2	0	8	36
13	0	0	0	10	3	17	0	2	1	4	37
14	0	0	1	6	1	8	2	2	0	2	22
15	0	0	1	1	0	14	0	0	5	0	21
16	0	0	1	1	1	6	0	1	3	6	19
Total	28	6	22	26	6	79	26	43	27	26	289

Appendix F

F5 : Mismatches for unskilled operators from questionnaire survey before the FBS experiment

Subject	Intrusion	Omission	Commis-sion	Reversal in sequence	Wrong request	Repeti-tion	Acts on wrong compo-nents	Mis-applicati on	Violation	Other mis-matches	Total
1	6	0	0	0	0	0	0	0	0	0	6
2	0	0	16	0	0	0	5	5	2	0	28
3	15	0	0	3	0	0	0	0	1	0	19
4	18	0	7	4	0	3	0	0	0	0	32
5	11	7	8	4	1	4	3	6	3	13	60
6	14	0	4	2	0	0	3	1	3	0	27
7	8	1	7	4	1	5	3	7	6	3	45
8	18	0	4	7	0	1	2	7	7	1	47
9	19	1	9	0	4	4	10	17	7	0	71
10	9	0	3	3	0	2	1	0	1	0	19
11	9	2	9	8	3	2	6	12	0	0	51
12	7	4	0	0	1	4	1	2	0	2	21
Total	134	15	67	35	10	25	34	57	30	19	426

Appendix F

F6 : Mismatches for unskilled operators from questionnaire survey after the FBS experiment

Subject	Intrusion	Omission	Commis-sion	Reversal in sequence	Wrong request	Repeti-tion	Acts on wrong compo-nents	Mis-applicati on	Violation	Other mis-matches	Total
1	1	0	0	1	0	0	0	0	0	0	2
2	4	0	18	0	0	0	5	0	1	1	29
3	8	0	0	1	0	1	0	0	0	0	10
4	12	0	0	0	0	0	0	1	0	0	13
5	8	2	6	3	4	4	1	4	4	18	54
6	10	1	0	5	0	0	0	0	1	0	17
7	7	0	0	6	0	3	0	1	3	4	24
8	12	1	5	0	0	8	1	4	3	0	34
9	15	1	2	2	2	6	7	7	6	0	48
10	9	0	0	2	0	2	0	0	0	0	13
11	6	2	6	7	0	8	3	12	0	0	44
12	8	2	0	0	0	2	0	5	0	2	19
Total	100	9	37	27	6	34	17	34	18	25	307

APPENDIX G

Evaluation sheet determining the level of automation for typical human functions in machining i.e. selection, set-up and inspection functions. Corresponding items in the questionnaire are indicated in the brackets.

Elements of tasks	Levels of automation (Fully manual ← → Fully automatic)										Mean Level
I. Tasks in selection functions											
1. First time right in selecting tools (1)	1	2	3	4	5	6	7	8 (O)	9 (X)	10	
2. Select correct work holding method(3)	1	2	3	4	5	6	7	8	9 (O)	10 (X)	
3. Select correct speed(5)	1	2	3	4	5	6	7	8	9 (O, X)	10	
4. Select correct feed(7)	1	2	3	4	5	6	7	8	9 (O)	10 (X)	9.2
5. Select direction of travel(12)	1	2	3	4	5	6	7	8	9	10 (O, X)	
6. Select tool holding method(16)	1	2	3	4	5	6	7	8	9 (O, X)	10	9.5
7. Select speeds for drills and reamers(18)	1	2	3	4	5	6	7	8	9	10 (O, X)	
8. Select components (i.e. sleeves)(19)	1	2	3	4	5	6	7	8	9	10 (O, X)	
9. Select angle of toolpost(24)	1	2	3	4	5	6	7	8	9 (O, X)	10	
II. Tasks in set-up functions											
1. Set-up tools to c/hts (2)	1	2	3	4	5	6	7	8 (O)	9 (X)	10	
2. Set cutting speed (6)	1	2	3	4	5	6	7	8	9 (O)	10 (X)	
3. Set cutting feed (8)	1	2	3	4	5	6	7	8	9 (O, X)	10	
4 Set tool datum to zero (9)	1	2	3	4	5	6	7	8	9 (X)	10 (O)	9.2
5. Set depth of cut (10)	1	2	3	4	5	6	7	8	9	10 (O, X)	
6. Engage /set-up clutch (11)	1	2	3	4	5	6	7	8	9 (O)	10 (X)	9.5
7. Engage / set-up feed (13)	1	2	3	4	5	6	7	8	9 (O, X)	10	
8. Engaging / set-up feeding manually (17)	1	2	3	4	5	6	7	8	9	10 (O, X)	
9. Determine and set feed (20)	1	2	3	4	5	6	7	8	9 (O)	10 (X)	
10.Engage and set feed to cut a taper (21)	1	2	3	4	5	6	7	8	9 (O, X)	10	
III. Tasks in inspection functions											
1. Checking diameter of stock material (4)	1	2	3	4	5	6	7	8	9 (X)	10 (O)	
2. Checking required length of cut (14)	1	2	3	4	5	6	7	8	9	10 (O, X)	9.8
3. Checking required diameter of w/piece(15)	1	2	3	4	5	6	7	8	9	10 (O, X)	
4. Checking depth of bore (22)	1	2	3	4	5	6	7	8	9 (X)	10 (O)	9.6
5. Checking diameter of bore (23)	1	2	3	4	5	6	7	8	9 (O)	10 (X)	

LEGEND :
- O Level indicated in questionnaires *before* the FBS experiment
- X Level indicated in questionnaires *after* the FBS experiment.

APPENDIX H

Tables (Siegel, 1956)

TABLE A. TABLE OF PROBABILITIES ASSOCIATED WITH VALUES AS EXTREME AS OBSERVED VALUES OF z IN THE NORMAL DISTRIBUTION

The body of the table gives one-tailed probabilities under H_0 of z. The left-hand marginal column gives various values of z to one decimal place. The top row gives various values to the second decimal place. Thus, for example, the one-tailed p of $z \geq .11$ or $z \leq -.11$ is $p = .4562$.

z	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
.0	.5000	.4960	.4920	.4880	.4840	.4801	.4761	.4721	.4681	.4641
.1	.4602	.4562	.4522	.4483	.4443	.4404	.4364	.4325	.4286	.4247
.2	.4207	.4168	.4129	.4090	.4052	.4013	.3974	.3936	.3897	.3859
.3	.3821	.3783	.3745	.3707	.3669	.3632	.3594	.3557	.3520	.3483
.4	.3446	.3409	.3372	.3336	.3300	.3264	.3228	.3192	.3156	.3121
.5	.3085	.3050	.3015	.2981	.2946	.2912	.2877	.2843	.2810	.2776
.6	.2743	.2709	.2676	.2643	.2611	.2578	.2546	.2514	.2483	.2451
.7	.2420	.2389	.2358	.2327	.2296	.2266	.2236	.2206	.2177	.2148
.8	.2119	.2090	.2061	.2033	.2005	.1977	.1949	.1922	.1894	.1867
.9	.1841	.1814	.1788	.1762	.1736	.1711	.1685	.1660	.1635	.1611
1.0	.1587	.1562	.1539	.1515	.1492	.1469	.1446	.1423	.1401	.1379
1.1	.1357	.1335	.1314	.1292	.1271	.1251	.1230	.1210	.1190	.1170
1.2	.1151	.1131	.1112	.1093	.1075	.1056	.1038	.1020	.1003	.0985
1.3	.0968	.0951	.0934	.0918	.0901	.0885	.0869	.0853	.0838	.0823
1.4	.0808	.0793	.0778	.0764	.0749	.0735	.0721	.0708	.0694	.0681
1.5	.0668	.0655	.0643	.0630	.0618	.0606	.0594	.0582	.0571	.0559
1.6	.0548	.0537	.0526	.0516	.0505	.0495	.0485	.0475	.0465	.0455
1.7	.0446	.0436	.0427	.0418	.0409	.0401	.0392	.0384	.0375	.0367
1.8	.0359	.0351	.0344	.0336	.0329	.0322	.0314	.0307	.0301	.0294
1.9	.0287	.0281	.0274	.0268	.0262	.0256	.0250	.0244	.0239	.0233
2.0	.0228	.0222	.0217	.0212	.0207	.0202	.0197	.0192	.0188	.0183
2.1	.0179	.0174	.0170	.0166	.0162	.0158	.0154	.0150	.0146	.0143
2.2	.0139	.0136	.0132	.0129	.0125	.0122	.0119	.0116	.0113	.0110
2.3	.0107	.0104	.0102	.0099	.0096	.0094	.0091	.0089	.0087	.0084
2.4	.0082	.0080	.0078	.0075	.0073	.0071	.0069	.0068	.0066	.0064
2.5	.0062	.0060	.0059	.0057	.0055	.0054	.0052	.0051	.0049	.0048
2.6	.0047	.0045	.0044	.0043	.0041	.0040	.0039	.0038	.0037	.0036
2.7	.0035	.0034	.0033	.0032	.0031	.0030	.0029	.0028	.0027	.0026
2.8	.0026	.0025	.0024	.0023	.0023	.0022	.0021	.0021	.0020	.0019
2.9	.0019	.0018	.0018	.0017	.0016	.0016	.0015	.0015	.0014	.0014
3.0	.0013	.0013	.0013	.0012	.0012	.0011	.0011	.0011	.0010	.0010
3.1	.0010	.0009	.0009	.0009	.0008	.0008	.0008	.0008	.0007	.0007
3.2	.0007									
3.3	.0005									
3.4	.0003									
3.5	.00023									
3.6	.00016									
3.7	.00011									
3.8	.00007									
3.9	.00005									
4.0	.00003									

TABLE K. TABLE OF CRITICAL VALUES OF U IN THE MANN-WHITNEY TEST* (*Continued*)

Table K$_{IV}$. Critical Values of U for a One-tailed Test at $\alpha = .05$ or for a Two-tailed Test at $\alpha = .10$

n_2 \ n_1	9	10	11	12	13	14	15	16	17	18	19	20
1											0	0
2	1	1	1	2	2	2	3	3	3	4	4	4
3	3	4	5	5	6	7	7	8	9	9	10	11
4	6	7	8	9	10	11	12	14	15	16	17	18
5	9	11	12	13	15	16	18	19	20	22	23	25
6	12	14	16	17	19	21	23	25	26	28	30	32
7	15	17	19	21	24	26	28	30	33	35	37	39
8	18	20	23	26	28	31	33	36	39	41	44	47
9	21	24	27	30	33	36	39	42	45	48	51	54
10	24	27	31	34	37	41	44	48	51	55	58	62
11	27	31	34	38	42	46	50	54	57	61	65	69
12	30	34	38	42	47	51	55	60	64	68	72	77
13	33	37	42	47	51	56	61	65	70	75	80	84
14	36	41	46	51	56	61	66	71	77	82	87	92
15	39	44	50	55	61	66	72	77	83	88	94	100
16	42	48	54	60	65	71	77	83	89	95	101	107
17	45	51	57	64	70	77	83	89	96	102	109	115
18	48	55	61	68	75	82	88	95	102	109	116	123
19	51	58	65	72	80	87	94	101	109	116	123	130
20	54	62	69	77	84	92	100	107	115	123	130	138

* Adapted and abridged from Tables 1, 3, 5, and 7 of Auble, D. 1953. Extended tables for the Mann-Whitney statistic. *Bulletin of the Institute of Educational Research at Indiana University*, 1, No. 2, with the kind permission of the author and the publisher.

TABLE C. TABLE OF CRITICAL VALUES OF CHI SQUARE*

df	Probability under H_0 that $\chi^2 \geq$ chi square													
	.99	.98	.95	.90	.80	.70	.50	.30	.20	.10	.05	.02	.01	.001
1	.00016	.00063	.0039	.016	.064	.15	.46	1.07	1.64	2.71	3.84	5.41	6.64	10.83
2	.02	.04	.10	.21	.45	.71	1.39	2.41	3.22	4.60	5.99	7.82	9.21	13.82
3	.12	.18	.35	.58	1.00	1.42	2.37	3.66	4.64	6.25	7.82	9.84	11.34	16.27
4	.30	.43	.71	1.06	1.65	2.20	3.36	4.88	5.99	7.78	9.49	11.67	13.28	18.46
5	.55	.75	1.14	1.61	2.34	3.00	4.35	6.06	7.29	9.24	11.07	13.39	15.09	20.52
6	.87	1.13	1.64	2.20	3.07	3.83	5.35	7.23	8.56	10.64	12.59	15.03	16.81	22.46
7	1.24	1.56	2.17	2.83	3.82	4.67	6.35	8.38	9.80	12.02	14.07	16.62	18.48	24.32
8	1.65	2.03	2.73	3.49	4.59	5.53	7.34	9.52	11.03	13.36	15.51	18.17	20.09	26.12
9	2.09	2.53	3.32	4.17	5.38	6.39	8.34	10.66	12.24	14.68	16.92	19.68	21.67	27.88
10	2.56	3.06	3.94	4.86	6.18	7.27	9.34	11.78	13.44	15.99	18.31	21.16	23.21	29.59
11	3.05	3.61	4.58	5.58	6.99	8.15	10.34	12.90	14.63	17.28	19.68	22.62	24.72	31.26
12	3.57	4.18	5.23	6.30	7.81	9.03	11.34	14.01	15.81	18.55	21.03	24.05	26.22	32.91
13	4.11	4.76	5.89	7.04	8.63	9.93	12.34	15.12	16.98	19.81	22.36	25.47	27.69	34.53
14	4.66	5.37	6.57	7.79	9.47	10.82	13.34	16.22	18.15	21.06	23.68	26.87	29.14	36.12
15	5.23	5.98	7.26	8.55	10.31	11.72	14.34	17.32	19.31	22.31	25.00	28.26	30.58	37.70
16	5.81	6.61	7.96	9.31	11.15	12.62	15.34	18.42	20.46	23.54	26.30	29.63	32.00	39.29
17	6.41	7.26	8.67	10.08	12.00	13.53	16.34	19.51	21.62	24.77	27.59	31.00	33.41	40.75
18	7.02	7.91	9.39	10.86	12.86	14.44	17.34	20.60	22.76	25.99	28.87	32.35	34.80	42.31
19	7.63	8.57	10.12	11.65	13.72	15.35	18.34	21.69	23.90	27.20	30.14	33.69	36.19	43.82
20	8.26	9.24	10.85	12.44	14.58	16.27	19.34	22.78	25.04	28.41	31.41	35.02	37.57	45.32
21	8.90	9.92	11.59	13.24	15.44	17.18	20.34	23.86	26.17	29.62	32.67	36.34	38.93	46.80
22	9.54	10.60	12.34	14.04	16.31	18.10	21.24	24.94	27.30	30.81	33.92	37.66	40.29	48.27
23	10.20	11.29	13.09	14.85	17.19	19.02	22.34	26.02	28.43	32.01	35.17	38.97	41.64	49.73
24	10.86	11.99	13.85	15.66	18.06	19.94	23.34	27.10	29.55	33.20	36.42	40.27	42.98	51.18
25	11.52	12.70	14.61	16.47	18.94	20.87	24.34	28.17	30.68	34.38	37.65	41.57	44.31	52.62
26	12.20	13.41	15.38	17.29	19.82	21.79	25.34	29.25	31.80	35.56	38.88	42.86	45.64	54.05
27	12.88	14.12	16.15	18.11	20.70	22.72	26.34	30.32	32.91	36.74	40.11	44.14	46.96	55.48
28	13.56	14.85	16.93	18.94	21.59	23.65	27.34	31.39	34.03	37.92	41.34	45.42	48.28	56.89
29	14.26	15.57	17.71	19.77	22.48	24.58	28.34	32.46	35.14	39.09	42.56	46.69	49.59	58.30
30	14.95	16.31	18.49	20.60	23.36	25.51	29.34	33.53	36.25	40.26	43.77	47.96	50.89	59.70

* Table C is abridged from Table IV of Fisher and Yates: *Statistical tables for biological, agricultural, and medical research*, published by Oliver and Boyd Ltd., Edinburgh, by permission of the authors and publishers.

TABLE G. TABLE OF CRITICAL VALUES OF T IN THE WILCOXON MATCHED-PAIRS SIGNED-RANKS TEST*

N	Level of significance for one-tailed test		
	.025	.01	.005
	Level of significance for two-tailed test		
	.05	.02	.01
6	0	—	—
7	2	0	—
8	4	2	0
9	6	3	2
10	8	5	3
11	11	7	5
12	14	10	7
13	17	13	10
14	21	16	13
15	25	20	16
16	30	24	20
17	35	28	23
18	40	33	28
19	46	38	32
20	52	43	38
21	59	49	43
22	66	56	49
23	73	62	55
24	81	69	61
25	89	77	68

* Adapted from Table I of Wilcoxon, F. 1949. *Some rapid approximate statistical procedures.* New York: American Cyanamid Company, p. 13, with the kind permission of the author and publisher.

TABLE K. TABLE OF CRITICAL VALUES OF U IN THE MANN-WHITNEY TEST*

Table K_I. Critical Values of U for a One-tailed Test at $\alpha = .001$ or for a Two-tailed Test at $\alpha = .002$

n_1 \ n_2	9	10	11	12	13	14	15	16	17	18	19	20
1												
2												
3									0	0	0	0
4		0	0	0	1	1	1	2	2	3	3	3
5	1	1	2	2	3	3	4	5	5	6	7	7
6	2	3	4	4	5	6	7	8	9	10	11	12
7	3	5	6	7	8	9	10	11	13	14	15	16
8	5	6	8	9	11	12	14	15	17	18	20	21
9	7	8	10	12	14	15	17	19	21	23	25	26
10	8	10	12	14	17	19	21	23	25	27	29	32
11	10	12	15	17	20	22	24	27	29	32	34	37
12	12	14	17	20	23	25	28	31	34	37	40	42
13	14	17	20	23	26	29	32	35	38	42	45	48
14	15	19	22	25	29	32	36	39	43	46	50	54
15	17	21	24	28	32	36	40	43	47	51	55	59
16	19	23	27	31	35	39	43	48	52	56	60	65
17	21	25	29	34	38	43	47	52	57	61	66	70
18	23	27	32	37	42	46	51	56	61	66	71	76
19	25	29	34	40	45	50	55	60	66	71	77	82
20	26	32	37	42	48	54	59	65	70	76	82	88

* Adapted and abridged from Tables 1, 3, 5, and 7 of Auble, D. 1953. Extended tables for the Mann-Whitney statistic. *Bulletin of the Institute of Educational Research at Indiana University*, 1, No. 2, with the kind permission of the author and the publisher.

TABLE K. TABLE OF CRITICAL VALUES OF U IN THE MANN-WHITNEY TEST* (*Continued*)

Table K_{II}. Critical Values of U for a One-tailed Test at $\alpha = .01$ or for a Two-tailed Test at $\alpha = .02$

n_1 \ n_2	9	10	11	12	13	14	15	16	17	18	19	20
1												
2					0	0	0	0	0	0	1	1
3	1	1	1	2	2	2	3	3	4	4	4	5
4	3	3	4	5	5	6	7	7	8	9	9	10
5	5	6	7	8	9	10	11	12	13	14	15	16
6	7	8	9	11	12	13	15	16	18	19	20	22
7	9	11	12	14	16	17	19	21	23	24	26	28
8	11	13	15	17	20	22	24	26	28	30	32	34
9	14	16	18	21	23	26	28	31	33	36	38	40
10	16	19	22	24	27	30	33	36	38	41	44	47
11	18	22	25	28	31	34	37	41	44	47	50	53
12	21	24	28	31	35	38	42	46	49	53	56	60
13	23	27	31	35	39	43	47	51	55	59	63	67
14	26	30	34	38	43	47	51	56	60	65	69	73
15	28	33	37	42	47	51	56	61	66	70	75	80
16	31	36	41	46	51	56	61	66	71	76	82	87
17	33	38	44	49	55	60	66	71	77	82	88	93
18	36	41	47	53	59	65	70	76	82	88	94	100
19	38	44	50	56	63	69	75	82	88	94	101	107
20	40	47	53	60	67	73	80	87	93	100	107	114

* Adapted and abridged from Tables 1, 3, 5, and 7 of Auble, D. 1953. Extended tables for the Mann-Whitney statistic. *Bulletin of the Institute of Educational Research at Indiana University*, 1, No. 2, with the kind permission of the author and the publisher.

TABLE K. TABLE OF CRITICAL VALUES OF U IN THE MANN-WHITNEY TEST* (*Continued*)

Table K_{III}. Critical Values of U for a One-tailed Test at $\alpha = .025$ or for a Two-tailed Test at $\alpha = .05$

n_1 \ n_2	9	10	11	12	13	14	15	16	17	18	19	20
1												
2	0	0	0	1	1	1	1	1	2	2	2	2
3	2	3	3	4	4	5	5	6	6	7	7	8
4	4	5	6	7	8	9	10	11	11	12	13	13
5	7	8	9	11	12	13	14	15	17	18	19	20
6	10	11	13	14	16	17	19	21	22	24	25	27
7	12	14	16	18	20	22	24	26	28	30	32	34
8	15	17	19	22	24	26	29	31	34	36	38	41
9	17	20	23	26	28	31	34	37	39	42	45	48
10	20	23	26	29	33	36	39	42	45	48	52	55
11	23	26	30	33	37	40	44	47	51	55	58	62
12	26	29	33	37	41	45	49	53	57	61	65	69
13	28	33	37	41	45	50	54	59	63	67	72	76
14	31	36	40	45	50	55	59	64	67	74	78	83
15	34	39	44	49	54	59	64	70	75	80	85	90
16	37	42	47	53	59	64	70	75	81	86	92	98
17	39	45	51	57	63	67	75	81	87	93	99	105
18	42	48	55	61	67	74	80	86	93	99	106	112
19	45	52	58	65	72	78	85	92	99	106	113	119
20	48	55	62	69	76	83	90	98	105	112	119	127

* Adapted and abridged from Tables 1, 3, 5, and 7 of Auble, D. 1953. Extended tables for the Mann-Whitney statistic. *Bulletin of the Institute of Educational Research at Indiana University*, 1, No. 2, with the kind permission of the author and the publisher.