THE OPTIMUM DISTRIBUTION OF TASKS AMONG OPERATORS IN A MULTIMAN-MACHINE SYSTEM

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SUMMARY

To ensure that tasks are distributed among operators in a team so that none is either overloaded or underloaded, it is essential that consideration is given to the demands imposed by tasks, and to their potential modification by the manner in which the team is organised.

Of primary importance are certain characteristics, or general properties of tasks, such as their complexity and organisation. Whereas the former refers to the information-processing demands imposed on the operator by each task independently, the latter refers to the inter-relationships between tasks. Two types of task organisation may be distinguished: intra-task organisation refers to the inter-relationships existing between the tasks of an individual operator, i.e. the extent to which they impose similar demands, whilst inter-task organisation is defined by the degree of interaction between team members.

A series of five experiments is described in which the effects of such task characteristics on the performance of two-man teams is investigated, using simulated command, control and communication tasks. Teams are organised in either vertical or horizontal manners. In the vertical method, the total task requirement is divided into functional categories and responsibility for certain functions is assigned to each operator. The output from the first operator is the input to the second. However, in the horizontal organisation, both operators may act simultaneously since the total task demand is divided between them, and the tasks of each operator may include all the functions required in the total task.

Experimental results generally favoured the horizontal organisation, but this superiority tended to diminish when intra-task organisation was low, when inter-task organisation was high, or when the high complexity of individual tasks led to an overall task complexity too high for effective time-sharing.

Key words : Multiman-machine system
Team organisation

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CHAPTER 1. INTRODUCTION

1.0

BACKGROUND

The question of task distribution can best be considered within the context of the general systems design procedure. Chapanis (1965) has defined the man-machine system as 'an equipment system in which at least one of the components is a human being who interacts with or intervenes in the operation of the machine components in the system from time to time'. The human and machine components of the system combine to transform inputs to the system into the required outputs, in order to achieve the objectives or purposes of the system. Once the objectives of the system have been clarified, the general means or actions by which the system is expected to fulfil its requirements must be specified, i.e. the stage known as 'separation of functions'. Singleton (1974) has defined a function as 'an activity or set of activities described strictly in terms of activities and not in terms of the means of achieving them'. In order to translate the description of the design problem from functional to physical terms, these functions must be allocated between the available mechanisms. The various techniques available for allocating functions between men and machines usually compare their relative advantages and disadvantages in performing various types of function. Thereafter, the development of both the personnel sub-system and the equipment sub-system continue simultaneously, together with the design of the man-machine interface. The main concern of this study is with the development of the personnel sub-system when that sub-system consists of a team as opposed to an individual operator. The team is the essential element of the multiman-machine system.

After functions have been allocated to the human element of the system, all the actions necessary to implement these functions must be considered. To do this, the system designer produces a task description. DeGreene (1970) has defined a task as 'a composite of related (discriminatory-decision-motor) activities performed by an individual and directed towards accomplishing a specific amount of work within a specific work context'. Thus, in designing a new system, the system designer will examine the anticipated stimulus inputs to, and the required outputs from, the system and conceptualise, through intuition or logic, what would be the behavioural mechanisms required to make the transformations, i.e. in a task description, it must be decided what the operator must perceive, discriminate, decide, and manipulate in order to accomplish the functions. Task descriptions provide a reference from which design and operational decisions can be made.

In the multiman-machine system, it is essential that tasks are distributed among team members so that none is overloaded or underloaded. It is important to discover the optimum combination of tasks in order to design jobs for each member of the team. This may involve some operators performing whole tasks, others part-tasks, and others more than one task. There may even be the addition of redundant personnel to perform a compensatory or fail-safe function. Task demands greatly determine the organisation of the team. When dependency between tasks is low, then team organisation is relatively unimportant, but when dependency is high, it is important that tasks are allocated among team members in the most optimal way. Therefore, in addition to the information on the content and psychological demands imposed by tasks on an individual operator, it is important that the task description describes tasks in terms of their general properties or characteristics, as these relate to the tasks as a whole and to task inter-relationships. Chapter1.3. describes the key task characteristics of complexity, dependency, divisibility and organisation. The manner in which the team is organised to process task demands will determine to a great extent the effectiveness of system performance. It is the aim of this study to produce some guidelines on the type of team organisation that is best able to cope with task demands of a particular nature. Chapter 1.4. describes possible types of team organisation. Also of importance are the attributes of the individual operators in the team, although their effects seem to be very much dependent on the way in which the team is organised. Consideration of these factors are beyond the scope of this study, but Chapter 1.5. describes the main findings in this area.

1.1

THE TEAM - A DEFINITION

When two or more individuals work together to accomplish a specific objective, they can be said to constitute a team or group. A sports team, a management team, a team of operators working in a computerised command, control and communication system (C^3), and a problem-solving group so widely used in social psychological research, have different objectives but all involve the interaction of individuals to achieve a common goal. It is this interaction that distinguishes a team or group from a collection of unrelated individuals, even though the latter may each be working towards the same objective, as in the case of a number of radar operators who perform the same task independently. A team, then, may be defined as 'a task-oriented organisation of individuals interacting to achieve a specific goal' (Horrocks and Goyer, 1959).

Briggs and Naylor (1964) similarly defined the team, but they emphasized the structural nature of its operating environment. 'The structure', they said, was 'formal in that an organisational scheme has been imposed on the individuals which defines the functions to be performed, the sequence in which the functions must occur, and the links by which the inter-individual interaction may occur.' Whilst differing degrees of formality in this sense can be envisaged in C^3, management, and sports teams, the problem-solving group exhibits little or no such formality. Klaus and Glaser (1968) have elaborated on this theme, distinguishing between the 'team' and 'small group' due to inherent differences between the two in structure and function. Teams, they say, generally:

i) are relatively rigid in structure, organisation, and communication networks, whereas groups have an indefinite or loose structure and organisation;

ii) have well-defined positions or member assignments so that the participation in a given task by each individual can be anticipated to a given extent. Groups have assumed rather than designated positions where the contribution of each individual to the accomplishment of the task is largely dependent on his own personal characteristics;

iii) depend on the co-operative or co-ordinated participation of several specialised individuals whose activities contain little overlap and who must each perform their task at least to some minimum level of proficiency. Groups mainly depend on the quality of independent, individual contributions;

iv) are often involved with equipment or tasks requiring perceptual-motor activities, whereas groups are often involved with complex, decision-making activities;

v) can be given specific guidance on job performance, based on a task analysis of the team's equipment, mission, or situation, whilst groups cannot be given much specific guidance beforehand, since the quality and quantity of participation by individual members is not known beforehand.

The typical abstract, problem-solving task used in studies of the small group, and the lack of interest in the system, means that the multitude of studies in this area are of little use to team researchers. Group studies are usually concerned with such factors as the size and composition of the group and their relation to the type of task to be performed. Unique or insightful solutions, often the result of such studies, are rarely required in the team situation where operators work in conjunction with equipment on tasks often involving repetitive application.

The degree of structural formality in team operations is linked to the amount of 'indeterminacy' in the operational environment. An indeterminate system is one in which the inputs to the system, operating procedures, and the responses required of individuals, vary over time. The probability of occurrence of such factors is high in a 'determinate' system. Consequently, the functioning of the system, and hence the team, is more predictable in a determinate system. Boguslaw (1961) has approached the dimension of determinacy by distinguishing between 'established' and 'emergent' situations. Established events are repetitive and predictable and the rules for handling them are specified and detailed. Emergent situations arise when 'all action-relevant environmental conditions have not been specified, the state of the system does not correspond to relied-upon predictions, and analytical solutions are not available.' A team working in a system environment which contains a significant proportion of emergent situations has been compared to a biological organism which develops and grows through adaptation. Kennedy (1962) considered the team to be 'a synthetic organisation of which the individuals are components.' Alexander and Cooperbrand (1965), in a paper concerned primarily with team training for emergent situations, expanded on this viewpoint, putting forward three concepts which they assumed to underlie the development process. Individual team members develop a 'system awareness' which includes the recognition of the effects of their own actions on other team members. To do this, they must understand the relative importance of the various system goals, as well as when and how to make the appropriate adjustments when they or another team member become overloaded. Secondly, a team member develops an 'integrated model of the environment', the accuracy of which determines the capability to anticipate events. A simplified model of the complex real situation is constructed in order to deal with it. The authors feel that if the effectiveness of the team is related to the ability of individual members to act co-operatively in dealing with the environment, they all ought to have the same environmental model, or models which result in facilitative rather than interfering behaviour. Finally, through the 'development of innovations', the team adapts to the environment by developing new and better techniques of organising and performing its activities. Other models postulating stages of team development have been advanced (Weiner, 1960; Jordan et al., 1963; Boguslaw and Porter, 1962) but all, with slight variations, follow the above format with an initial individual sensitivity to the operating environment preceding a team consensus. Finally, the 'mature' team develops co-operative strategies to deal with a wide variety of situations. Such models may be applied to teams operating in both emergent and established situations but, clearly, they are primarily intended to describe the development of work procedures and adaptive innovations, such as improvisation and impromptu response invention, by team members in the former type of situation.

Whatever team definition one adopts would appear to depend on the focus of research interest. The organismic model is more appropriate when one is more concerned with the processes of individual and team development - a glass-box approach, whilst other definitions, where the team is viewed as a single response unit, are more appropriate to investigations of the overall performance of a team in a relatively established situation. All definitions do tend to agree on certain key aspects of team behaviour. It is directed towards the attainment of specific goals within a formal or informal structure, the degree of formality depending on how far the operations and the sequence in which these operations occur can be specified in advance. Individual team members have assigned roles and for goal attainment, interaction or co-operation between operators is usually required.

1.2

DETERMINANTS OF TEAM PERFORMANCE

An early attempt to define the constituent elements of multiman (group or team) performance was made by Steiner (1966) who advanced three classes of determinants: task demands, resources and process. Task demands are the requirements imposed on the team by the task itself, whilst the resources of a team include all the relevant knowledge, abilities, skills or tools possessed by its individual members who are attempting to perform the task. The demands of the task specify the kinds and amounts of resources that are needed, and the utilization pattern that is required for optimal performance. Process consists of the individual or collective actions of the team members which, for Steiner, were principally the communicative interactions between them. Shiflett (1979) defined resources in a similar manner to Steiner but, rather than process, he used the term 'transformers' to encompass all the variables intervening between the resources and the outputs of the team. Included among transformers are constraints imposed by the organisation of the team and task, as well as certain personal characteristics of team members which influence the utilization of resources. The 'interaction process' has also been described by Hackman and Morris (1976) in their review of group performance effectiveness. Group interaction processes are seen as acting upon three classes of focal variables - the design of the task, the norms of the group, and group composition, which includes member abilities relevant to the task, personality variables and leadership - with three associated classes of summary variables - level and utilization of member knowledge and skill, nature and utilization of task performance strategies, and level and co-ordination of member effort - to determine group performance. Structural role theory (Oeser and O'Brien, 1967) similarly considers the 'group task system' to be a function of the group task, personal attributes of the team members, and the positions, or organisation, of these individuals in the group.

These related theoretical analyses provide a useful framework for studies of multiman situations in general. However, researchers in the team area, with the more formal structure of the working group, have not tended to consider composition factors. Glaser et al. (1955), for example, describe team processes in terms of the communication flow between team members (number of communication links, the frequency and centralisation of communication), the amount of co-operation required of team members, and the extent to which a team operation can be differentiated into different classes of activity. The inter-dependency of such factors was recognised by Naylor and Dickinson (1969) whose model regarded team performance to be a function of task structure, work structure, and communication structure. Whereas task structure refers to the demand characteristics of the task to be accomplished, work structure was defined as the manner in which the task components are distributed among team members. The communication structure was defined in terms of the communication inter-relationships which exist between team members and, as such, was viewed as a dependent variable on the task and work structure variables.

All the models, with minor variations in terminology and emphasis, seem to agree that the four key elements determining team performance are :

i) the task demands;

ii) the team organisation;

iii) the communication structure, and;

iv) the composition of the team.

It is the interaction between the task demands and the three latter variables that determines the load imposed on the system by the tasks to be performed (see Fig. 1.2.1.). This view is supported by at least two authors in their consideration of the concept of load. In trying to resolve the ambiguities arising in the definition of load, Leplat (1978) has distinguished between load as characteristic of the task, i.e. the obligations and compulsions the task imposes on the operator, and load as consequence for the operator in performing the task. Leplat terms the former 'work requirements' and reserves the term 'load' for the latter. Similarly, Welford (1978) discusses problems in the measurement of load in terms of two basic approaches. With the

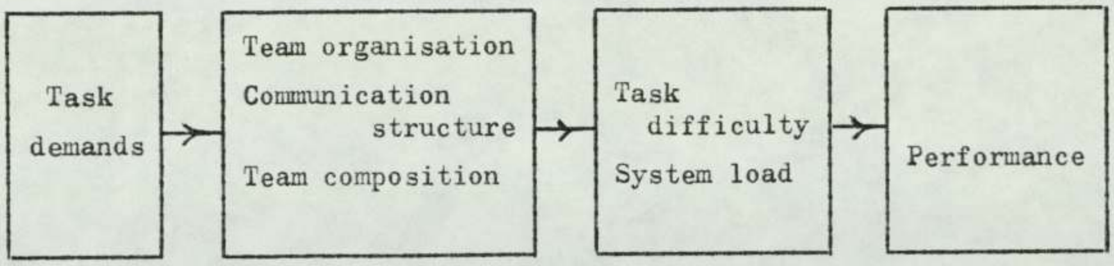


Fig. 1.2.1: Relationship between task demands and system performance in the multiman - machine system

'synthetic' approach, the load imposed by the task as a whole is calculated from the requirements imposed by its components, whilst the 'analytic' approach studies the task as a whole and components are analysed from the performance of the whole. Welford, then, also distinguishes between the original objective demands of the task, and their modification by the differing skills and capacities of operators, and the strategies utilised by them to perform the task. Both authors consider the interaction between the task and the individual operator, but their views are equally applicable to the team, or multiman, situation.

The distinction between the objective nature of 'task demands' and the subjectivity of operator responses can also be used when considering the 'difficulty' of a task. Like load, task difficulty also contains a subjective component. To call one task 'difficult' and another task 'easy' is to make a meaningless distinction between the tasks. To give an obvious example of this, the task of flying an aeroplane would be perceived, and experienced, as more difficult to perform by an untrained novice than by a trained pilot. The task demands are the same for both individuals, but the differing transformations make the load, and difficulty, of the task clearly greater for the former.

In order to optimise system performance on a given set of tasks, in terms of the speed and accuracy of responses, the system designer should endeavour to minimise the level of load on the system, and to reduce the difficulty of tasks to be performed to acceptable levels. In the multiman-machine system, it is important that due consideration is given to the demands imposed by required tasks, and to the most efficient methods of carrying them out. To do this, the organisation, communication structure, and composition of the team, and any interactions with the demands of the task need to be considered. In the remainder of this chapter, these constituent elements will be discussed in greater detail.

1.3

TASK DEMANDS

A task, or set of tasks, will impose certain demands on the information-processing capacities of the operator or team. These may include perceptual demands concerned with the searching for and receiving of information and the identification and discrimination of incoming data, translatory or mediational demands for relating perceptions to appropriate responding actions by processes of decision-making or choice, motor demands involving simple or complex, discrete or continuous movements, and demands on memory. Of particular relevance to the multiman system are communication demands where operators may be required to advise, answer, or request information from, each other.

A specific task can be described in terms of its content, and the types of psychological demands it imposes on the operator. Task analyses usually take the form of describing the elements of a task in terms of the initial stimulus to the operator, which triggers performance of the task, the required response to that stimulus with the procedure required to perform that response, and a statement of the goal or purpose of the task. Such fundamental descriptions, though, do not define the properties that differentiate one task from another. For example, one can compare a compensatory tracking task with a choice reaction time task. Although the tasks differ in specific content, they could impose equal or unequal demands on the information-processing capacity of the operator. We therefore need to describe tasks in terms of their general properties or characteristics, as these relate to the task as a whole, and to task inter-relationships. The remainder of this section will describe in detail the key task characteristics of complexity, dependency, divisibility, and organisation.

a) Task complexity

Naylor and Briggs (1963) propose that nearly all tasks could be considered as being made up of several subtasks and have defined the complexity of a task as 'the demands placed on information-processing and/or memory storage capacities by each of the task dimensions independently', Task complexity can vary with changes in task demands at any stage of information-processing from the input to the response levels. Among the many ways in which it can be increased are through changes in the number of inputs, increases in the number of required subtasks, incompatibility between inputs and required responses, and increases in the number and type of responses required.

i) Input complexity: there has been a multitude of investigations on the effects on performance of changes in the characteristics of inputs to the system. Studies have been mainly concerned with the number of inputs and their rate of presentation, the number of channels through which inputs are presented, and the effects of display factors. The type of input, e.g. in terms of structure and regularity, also affects system performance. Indeed, total input complexity usually arises from a combination of, or interaction between, factors contained in all these areas. An overview of the main findings follows, together with the names of authors who have performed representative pieces of research.

Since there is a limit to the extent to which an operator can divide his attention, it follows that an overload will occur at some point when the number of channels to be attended to is increased (Yntema and Schulman, 1967; Tickner and Poulton, 1973; Kanarick and Petersen, 1969). Similarly, the limited capacity channel of the operator for processing information will become overloaded when the rate of input presentation is increased (Huntley, 1972; Nicholson, 1962). Too low a rate of input presentation will also lead to reduced performance as in the vigilance task (Mackworth, 1968). However, such findings often depend on the type of input. When inputs are structured, as with alphanumerics, they have a high degree of regularity and redundancy. Operators are able to understand their meaning more easily than when inputs are unstructured, as with contacts appearing on a radar scope. The latter type of inputs are irregular and require further analysis and interpretation. Similarly, the more variability over time between inputs, the more complex the task, because of the need to integrate their varying dimensions.

Conversely, patterning of inputs, e.g. the repetition of identical inputs over time, reduces task complexity. The presence of irrelevant input information also increases task complexity since, unlike relevant information, it cannot be related directly to the task. Discriminatory demands would be higher if there was a high degree of similarity between inputs, or if inputs were of low intensity, as in vigilance tasks. Variations in the size, shape, colour or brightness of inputs also affect the discriminatory demands imposed on the operator. To summarise, operators working in an uncertain system environment where inputs are unstructured, variable, and often irrelevant, have a higher probability of error in responding to these inputs.

The accuracy of assimilation, and extraction of input information decreases as the number and density of inputs displayed to the operator is increased (Poulton, 1968), and this appears to be more so when inputs are in symbolic as opposed to alphanumeric form (Monty et al., 1967). Although vertical versus horizontal arrangement of material does not appear to produce differences in performance (Coffey, 1961), search times do increase when pertinent data is near the bottom of the display, or when the number of columns to be searched is increased (Ringel et al., 1966). Coding of updated input information, e.g. by colour or shape, can reduce input complexity by making changes more conspicuous to the operator. Similarly, the use of graphic (spatially-coded) displays has been shown to improve the performance of operators, especially in the speed and accuracy of recall of the displayed material (Newman and Davis, 1962). Line-type graphs and vertical bar graphs seem to be the most suitable (Schutz, 1961). Other studies in this area have compared the scanning of group and individual displays (Smith and Duggan, 1965), and the effectiveness of auditory displays whose advantages over visual displays largely depend on the type of task (Colquhoun, 1975).

ii) Procedural complexity: in a relatively determined system environment, operating procedures may be inflexible because the types of input and types of responses required are known. However, in an indeterminate system environment, it may not be possible to entirely specify types of inputs and responses, and consequently some modifications to operating procedures may be required during system functioning. Such modifications can either add to complexity, and cause operators to make more errors in selecting the optimum procedure to be followed, or the flexibility may reduce complexity if operators are able to respond more effectively. Complexity would be expected to vary with the degree of compatibility between inputs and responses. Since incompatibility would be expected to increase with a wider range of inputs and responses, greater flexibility in operating procedures should counterbalance its effects and so reduce complexity.

iii) Response complexity: many of the characteristics of inputs also apply to the complexity imposed by response requirements. Complexity will increase with the number and rate of required responses, as well as with the duration of each response (Adams et al., 1961). When there are several modes of responding, e.g. graph-plotting, verbal reporting, or when the number of response channels increases, e.g. verbal reports to various sources, complexity rises. The extent to which responses can be pre-programmed, i.e. the type of response can be specified in advance of the input, reduces complexity, as opposed to a system environment where responses are contingent on deviations in input characteristics. The latter situation would occur when adaptive responses are required to deal with uncertain, or emergent situations.

b) <u>Task dependency and Temporal Relations between tasks</u>

Complexity will obviously increase to some extent when there is an increase in the number of tasks to be performed, but the load imposed on the operator may vary depending on whether tasks are to be performed sequentially or in a concurrent manner. A sequential task must be performed in sequence with other tasks, either before a certain task or after another task, whilst concurrent tasks are performed at the same time as other tasks. Such variations in temporal relations would impose different demands on the limited time available to the operator.

Temporal relations are often determined by the dependency relationships existing between tasks. Sequential tasks are usually wholly or partially dependent on the completion of a previously occurring task, i.e. no reports can be made until raw contact data has been plotted. When tasks are performed concurrently, they are usually independent from each other but there may be occasions when completion of part of one task may be required before parts of the concurrent task can be processed. The utilisation of a concurrent, or secondary task, as a resource limiting device is often used as a technique in the measurement of the mental workload imposed by a primary task (e.g. Rolfe, 1971; Brown, 1978).

c) <u>Task divisibility</u>

Steiner (1966) has made a distinction between 'unitary' and 'divisible' tasks. The former type of task is one which cannot profitably be divided into subtasks and performed in piecemeal fashion by two or more operators, whilst the latter can be effectively sub-divided to permit a division of labour among operators. Both types of task, though, can be performed by a team. Although a unitary task can be performed in total by a single operator, additional operators may be added to perform the same task with identical input information so that the team operates in a redundant fashion. This is often the case in vigilance-type tasks, e.g. in radar operations or industrial inspection, when it is hoped to increase the accuracy of responses on the basis of 'N heads are better than one.' Operators may interact and work together as a team, or they may work independently in a 'multi-individual' rather than a 'team' situation. The most obvious divisible task is one where different sub-tasks may be performed by different team members, although the above vigilance-type tasks may also be thought of as divisible if, for example, operators divide the display between them, each being assigned an area of responsibility. In this case, each will perform the same type of task simultaneously but with different input information.

If overall task complexity is too high for one operator, then clearly a division of the task should reduce the level of complexity for an operator, but this reduction may be tempered if there is a resultant need for communication between operators. The extent to which tasks can be divided is of great importance in deciding how to allocate them among team members, i.e. how to organise the team.

d) Task organisation

Whereas an increase in task complexity usually results in an increase in the difficulty, or load, of the task on the operator, an increase in task organisation can increase or decrease task difficulty depending on its effects on the complexity of the task. Task organisation has been defined by Naylor and Briggs (1963) as 'the demands imposed on the operator due to the nature of the inter-relationship existing among the several task dimensions'. Tasks vary in their relationships to each other, on how much they influence each other, or on the extent to which they impose similar demands (i.e. perceptual, translatory, motor and memory demands) on the operator. The greater the degree of overlap existing among the demands imposed by the subtasks, the greater the amount of redundancy in the total task, and the less complexity. On the other hand, two subtasks would be completely unrelated if one could be performed with complete disregard for the other.

Naylor and Briggs (1963) originally studied task organisation in their investigations of the relative efficacy of part and whole training methods. They were concerned with the relationships between the components of a single task as performed by a single operator, what Steiner (1966) would term a 'unitary' task. In later work, Naylor and Briggs (1965) investigated team training and viewed their earlier part/whole studies as being analogous to a team, or multiman, situation. Whilst the complexity definition remained the same, they manipulated task organisation by varying the amount of co-operation or interaction between team operators. The earlier relationships between subtasks became relationships between different positions in the team.

Drawing mainly on the work of Naylor and Briggs, Meister (1976) distinguishes between two forms of task organisation - intra-task organisation and inter-task organisation. The first refers to the manner in which subtasks or task components relate to each other in their performance by a single operator, whilst the second is defined by the degree or manner of interaction among two or more team members. The tasks to be performed in the latter case are 'divisible' (Steiner, 1966) and permit a division of labour among operators. These distinctions are essentially the types of task organisation discussed by Naylor and Briggs in their earlier part/whole and later team training work. Tasks must have some degree of inter-task organisation for a team situation to occur. However, whereas the occurrence of inter-task organisation will usually add to the complexity of the task, intra-task organisation will often reduce the level of complexity of the total task, especially when tasks are performed concurrently. At low levels of complexity, though, the effects of intra-task organisation are not evident.

Greater flexibility in task organisation in computer-assisted, multiman-machine systems is now possible through the design of software. This is important to this study because of the relationship between task organisation and the organisation of the team. It should be possible to implement findings from the latter area by altering the task organisation at the system design stage, e.g. reduce operator interactions (inter-task organisation) by combining different tasks (according to their intra-task organisation) so that they can be performed by a single operator.

e) <u>Task demands and the multiman-machine system</u>

It can be seen from the foregoing analysis of the various properties of tasks that the total task demands imposed on the system depends on the interaction between the various task characteristics. Task complexity is the main characteristic contributing to task demands - the words 'complexity' and 'demands' are almost synonymous - but it can be modified, either positively or negatively, by the other task characteristics. Whilst complexity depends mainly on the complexity of inputs, procedures, and responses, and increases with the uncertainty of the system environment, it can be influenced by such factors as the temporal relations between tasks, the extent to which tasks can be divided, and the amount of organisation (intra-task organisation) between tasks. These factors can either reduce or increase complexity. For example, when tasks must be performed concurrently, an increase in complexity usually results, whilst the division of tasks will reduce complexity unless the possibly resultant need for communications (inter-task organisation) between operators outweighs the advantages by imposing higher levels of complexity.

Task demands are translated into the subjective experiences of load, or difficulty, by the operator. Individual differences between operators (see Chapter 1.5. Composition Variables) mean that operators will vary in their capacities and susceptibility to overload, and in the strategies they employ to cope with excess load. Among these are (i) response selection, where the operator will only make what he considers essential or high-value responses; (ii) omissions, where responses may be omitted, as compared to filtering, where only certain aspects of the required response to a stimulus will be made, and; (iii) queuing, where inputs will be allowed to accumulate or build-up whilst other responses are made.

Such operator behaviours are found in the multiman system at individual operator positions. However, the main interest of this study lies in the manner in which the team can be organised to modify the effects of complexity and so reduce load on the system. This can only be done by taking into account the complicated interactions between task characteristics.

1.4

TEAM ORGANISATION

If tasks are not allocated between team members in the most optimal way, there may be an uneven distribution of task demands on the system. This may result in an overloading of some operators and an underloading of others, leading to the multiman-machine system functioning at less than maximum efficiency. Although the organisation of the team depends to a great extent on the characteristics of the tasks to be performed, i.e. whether tasks are unitary or divisible, sequential or concurrent (temporal relations) and the dependency relationships between tasks, there are two basic forms of team organisation which can be employed; a vertical or serial arrangement of operators, and a horizontal or parallel arrangement.

a) Vertical and horizontal team organisations

The vertical method of team organisation is based on a functional classification of activities where the first operator must perform his function before a second operator can act. The input to the latter is the output from the first operator, the total task having been divided into sub-tasks and a sub-task assigned to each individual. In the horizontal organisation, the two operators may work simultaneously, their individual outputs not necessarily being subjected to further processing by another operator. Here, the total task demands have been divided in some way between the two operators so that each operator task may include all the functions required in the overall task. In most operational situations, a large team will utilise a combination of vertical and horizontal structures. The two types of team organisation will now be considered in relation to their employment on both unitary and divisible tasks.

Unitary tasks: as described previously, unitary tasks are those tasks which can be performed in their entirety by one operator. Although they do not lend themselves to a division of labour between operators, as do divisible tasks, there are occasions when a multiman situation may be employed to carry them out. Operators may be required to perform identical tasks with identical input information if, for example, a high degree of accuracy in responses is important, as in vigilance tasks typical of those carried out by industrial inspectors or the radar operator. The team will be operating in a redundant fashion. Fig. 1.4.1. shows two possible methods of organising the team to perform a unitary task. The vertical organisation would be typical of an inspection task (Task A) where an item would be initially inspected by Operator 1 prior to its being checked by Operator 2 to produce a single output, whilst the horizontal organisation would be one where the same item is inspected simultaneously by both inspectors. Whilst there is only one possible output with the vertical organisation, there may be two outputs

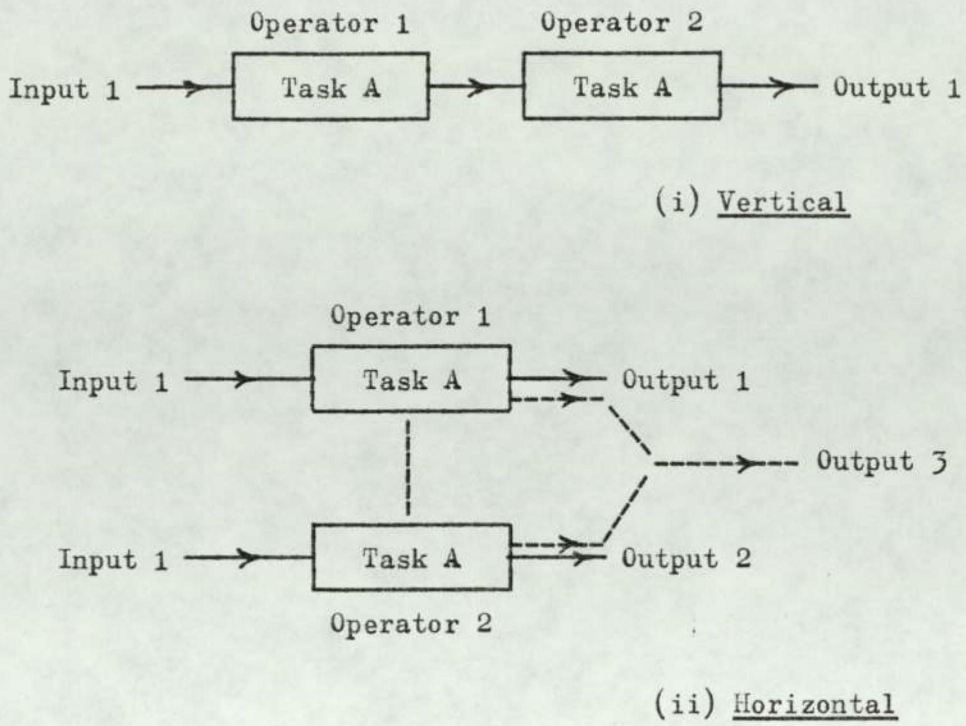


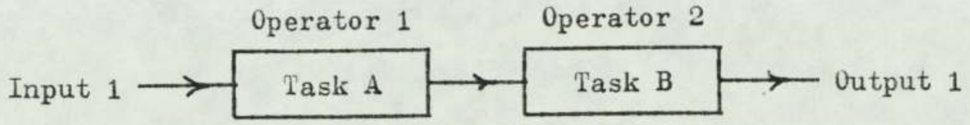
Fig. 1.4.1: Types of team organisation - Unitary tasks

with the horizontal organisation, or a single output (Output 3) if the two operators interact (broken line) and discuss their recommendations rather than act in an independent manner.

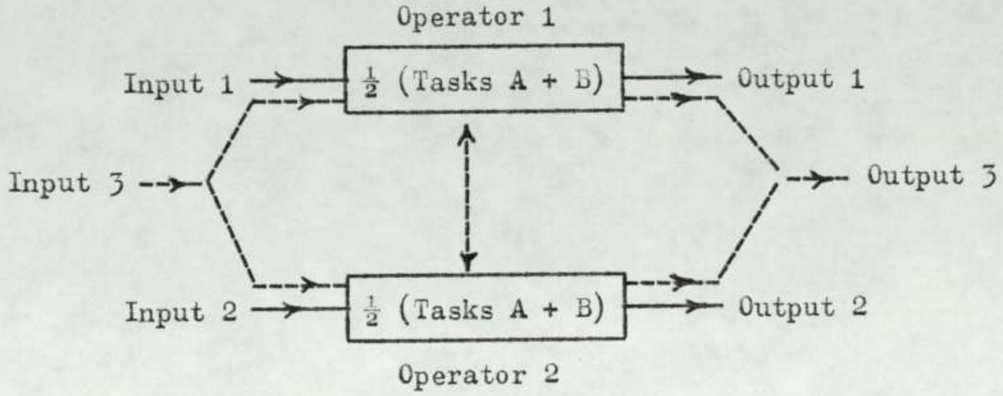
Of primary interest in tasks such as these have been the effects of interaction, as opposed to independence, between operators and in how team outputs are affected by the combination of responses from independent horizontal operators (see Chapter 2.1. page 37). Both operators may be required to respond correctly, or the team output may depend on the most productive, or best, team member. In the latter case, the task is said to be 'disjunctive', as compared to when the team output depends on the performance of the least productive member, in which case the task is said to be 'conjunctive'.

Divisible tasks: the range of possible team organisations with divisible tasks depends to a great extent on whether the constituent tasks are sequential or concurrent and on the dependency of the individual tasks on one another.

Fig. 1.4.2. demonstrates both vertical and horizontal arrangements of two-man teams performing two tasks, denoted Tasks A and B. The tasks are sequential and temporal relations are such that B must always follow A. The performance of B is assumed to be dependent on prior completion of A but this need not always be the case. In the vertical organisation, tasks have been allocated to the two operators so that Operator 1 performs A with his output becoming the necessary input for Operator 2 to perform B - there is, of necessity, an interaction between the two operators. The separation of the two tasks introduces inter-task organisation (see Chapter 1.3(d)) into the system. In the horizontal organisation, both tasks A and B are performed by each operator but the total task demand is shared. Typical of such an arrangement would be the plotting and reporting of radar information when each operator is responsible for half the geographical area of the display, or for half the number of tracks appearing. Operators may work independently with Operator 1 using input 1 to produce output 1, and Operator 2 using his different input 2 to produce a separate output 2. The broken lines, though, show some possible interactions between operators. If inputs have to be sorted (Input 3), there will be interaction between operators at the input level, or there may be interactions at the output level. Interactions at the output level have been studied extensively in the series of studies on team training by Briggs et al. (1965-1968) described in Chapter 2. page 52.



(i) Vertical



(ii) Horizontal

Fig. 1.4.2: Types of team organisation - Divisible Sequential tasks

The simplest form of interaction (or inter-task organisation) would be when the two operators, although working in an essentially independent manner, are free to help each other - the central broken line shows this form of interaction.

When tasks are to be performed concurrently, the vertical team organisation is not applicable, but this provides another variation on the horizontal team organisation. In Fig. 1.4.3, tasks A and B are required to be performed concurrently. A has been allocated to Operator 1: B to Operator 2. If the two tasks are completely independent from each other, and if each operator has all the required input information to perform the task (inputs 1 and 2), there is no need for interaction between operators. However, if

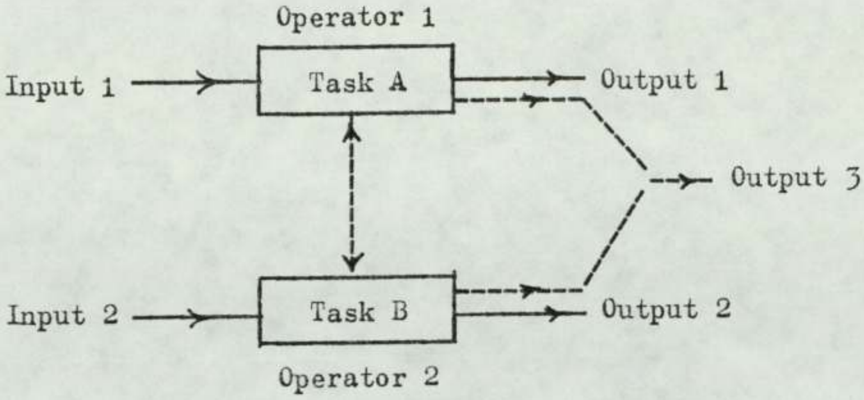


Fig. 1.4.3: Horizontal team organisation - Concurrent tasks

the two tasks, or parts of the two tasks, are dependent on each other in some way, or if Operator 2 possesses some information required by Operator 1 (or vice-versa), there will be interaction between the two operators. Similarly, there may be interaction at the output level if the two operators interact to produce a single team output (broken line). The communication networks studies and the series of studies by Lanzetta and Roby (1956-57) used experimental tasks of this type to investigate the effects on team performance of differing communication links and the dispersal of input information (see Chapter 2.3. page 52).

A further case of horizontal organisation on concurrent tasks arises when what is essentially a unitary task is divided between two or more operators so that the complexity of the task is shared between them. The team organisation, different inputs, and possible modes of interaction (see Fig. 1.4.4.) are similar to that shown in Fig. 1.4.3, but with a possible need to sort inputs (Input 3). However, the main difference is in the task to be performed. Whereas operators 1 and 2 perform different tasks in Fig. 1.4.3, those operators in Fig. 1.4.4. are each performing what is

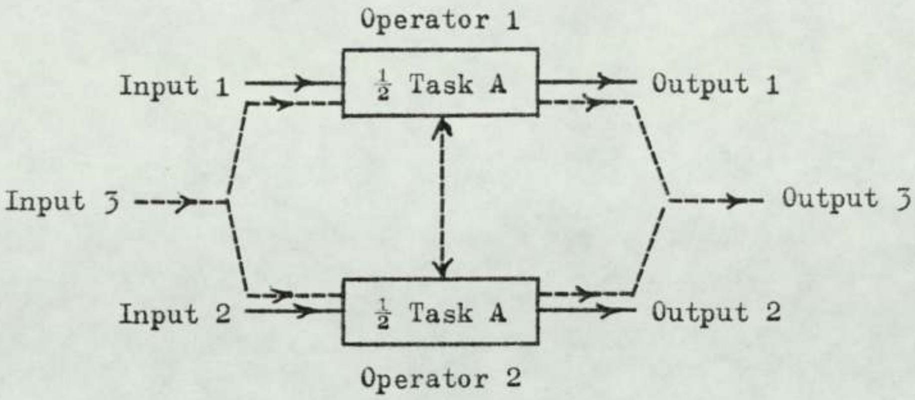


Fig. 1.4.4: Horizontal team organisation - Division of a single task

essentially the same task but with different inputs. Such a situation is typical of two radar operators making identifications in different sectors.

b) Communication structures

It can be seen from the examples above that the type of team organisation, the type of information available to operators, the dependency between tasks, and the type of response required may each influence the type of interaction or communication structure that develops within the team. A vertical organisation will always require a communication link between the two operators, but horizontal operators may be able to work independently. However, the other factors described often mean that some form of communication, e.g. at the input level or at the output level, is required in this organisation. The degree of communication can be considered as a dependent variable on the organisation of the team. As such, it reflects the co-operation or interaction between team members in performing their required tasks, although there may also be communications which are not relevant to task performance.

i) Type of co-operation: O'Brien (1968) has defined co-operation in a team as 'the degree to which the efforts of individual members are integrated with the other members in accomplishing the team goal'. He has also distinguished between two forms of co-operation: collaboration and co-ordination. Collaboration occurs when some positions in the team are given joint responsibility for certain tasks, i.e. members are required to work together at the same time, whilst team members would be required to co-ordinate their actions when 'the tasks allocated to different positions need to be sequenced by definite precedence relationships'. In the latter, team members would co-operate not by sharing the component tasks but by co-ordinating their tasks so that the workflow is smooth and continuous. In this sense, operators working in a vertical team organisation, where tasks have definite precedence relationships, would be required to co-ordinate their actions. Co-ordination in the horizontal organisation would be required when operators are required to interact at the output level when performing sequential tasks (see Fig. 1.4.2) or when there is some degree of dependency between concurrent tasks (see Fig. 1.4.3). The only true 'collaboration' would occur when interaction occurs between horizontal operators performing the same unitary task (see Fig. 1.4.1). However, in this study the term 'collaboration' is interpreted widely to include all task-relevant interactions between operators which have no precedence relationships.

ii) Volume and pattern of communication: communications between operators in a team are usually thought of as verbal but the interaction can also take place by visual means. This is particularly so when the team is working in a computerised system where the greater flexibility available means that information can be transmitted between operators through visual displays such as the visual display unit. Studies have been carried out to determine the relative efficacy of verbal and visual methods of conveying information (see Chapter 2, page 57). The other main area of interest has been on whether the amount and type of verbal communications affects team performance (see Chapter 2, page 57). In order to quantify verbal communications, investigations have attempted to construct taxonomies of the types of communications made by teams. An early taxonomy was developed by Bales (1950), whose work resulted in eight categories of communication (agrees, disagrees, suggests, etc.) and four categories of behaviour (shows tension, shows antagonism, etc.), for groups engaged on problem-solving tasks. Of more relevance to the multiman-machine system, though, was the attempt by Krumm and Farina (1962) to apply this to a content analysis of communications of a four-man team on a simulated B-52 mission. They developed seven categories of information transmission (requests information, provides information, volunteers information, irrelevant remarks, etc.). A full description of this taxonomy is given in Appendix XIII. Federman and Siegel (1965) developed a taxonomy of twenty-eight categories of communication when observing intra- and inter- crew interaction between two helicopters on simulated anti-submarine warfare operations. However, their methodology has been criticised by Briggs and Johnston (1966) who feel that no attempt has been made to discover the basic dimensions of the communication categories. They analysed team communications on their simulated air intercept task, applying factor analyses to an original forty-eight categories to arrive at five major dimensions (identification, error, irrelevant, declarative and tactical). Despite the criticisms that may be levelled at each category system, all do provide useful data of interaction in the type of systems for which they were designed. An investigator may modify them to satisfy his own needs - a modification of the Krumm and Farina category is used in one of the experiments in this study (see Chapter 3.4. page 112).

1.5

TEAM COMPOSITION

The composition of the team refers to the personal attributes of the individual team members. Among the attributes investigated by researchers in this area are those relating to the abilities, skills and experience of individuals, and such factors as their sex, status, and demographic background. However, most of the research has been concerned with aspects of personality, i.e. the traits, needs, attitudes and feelings of the individual.

In the social context of the team, individuals with their unique characteristics, are required to interact. It is the nature of this interaction which determines the behaviour of the team, and this may affect the team performance. The strength of this effect, though, appears to depend on the demands of the task and on factors relating to the organisation of the team. This can be demonstrated by some illustrative examples of attempts to answer two key questions in this area: (i) what combinations of individuals with different skills and proficiency levels produce the most effective teams? and;(ii) what characteristics of individuals produce compatibility between team members?

Relatively little research on the former problem has been reported, but it appears that the way in which the team is organised determines the extent to which individual member proficiencies affect overall performance. Whether the team is organised in a horizontal or vertical fashion affects the pattern of co-operation, or interaction, between team members, (see Chapter 1.4. page 28). Whereas a vertical team organisation calls for co-ordinative activities between team members, a horizontal organisation is usually typified by co-operation of a collaborative nature. O'Brien and Owens (1969) found that when team members were asked to collaborate in task performance, the influence of individual member abilities was reduced. This was due to processes of compensation between the levels of achievement of the lesser and more proficient members. The performance of such a team would not be as high as it would be with a group of all high proficiencies, or as low as a group of all low proficiency members. Alternatively, co-ordination among team members increases the importance of member proficiency. Here, as in the vertical team organisation, all members must successfully complete their task for a team output to be produced. A low proficiency member would be 'a weak link in the chain'.

A number of studies, cited by Hackman and Morris (1976) have shown that it is possible to predict team performance from individual proficiency if the task levies demands on the proficiency of specific individuals. This is not possible, though, if substantial interaction is required between members. Jones (1974), for example, attempted to predict the performance of athletic teams from data on the proficiency of individual team members. Whilst teams with better athletes usually did better, the level of prediction attained for some sports was higher than for others. Nearly 90% of the variation in baseball team effectiveness was predictable from measures of team member proficiency, compared to 35% for basketball teams. The author attributes the difference to the fact that personal relations and teamwork, i.e. collaborative interaction, are required for success in basketball with more independence of functioning being possible in baseball.

Attempts to answer the second question have produced an extensive amount of research on the impact of many specific individual attributes on team functioning. Research has been mainly concerned with the question of homogeneity or heterogeneity of team member attributes and, as such, is closely linked to various social psychological theories of interpersonal attraction. A theory of similarity or 'strain towards symmetry' has been advanced by Newcomb (1961), in which the individual is conceived to need support from others for his attitudes and beliefs. When two individuals have similar attitudes, pressures towards balance arise which tend to generate interpersonal attraction. When dissimilar attitudes exist, pressures towards balance tend to generate interpersonal hostility or dislike. On the basis of the old adage 'birds of a feather flock together', one would therefore expect a team composed of members homogeneous in attributes to be more cohesive. When individuals are similar in this way, a 'congruent' relationship exists, e.g. two individuals high in sociability should establish a mutually satisfactory relationship. However, personality characteristics may be said to be 'competitive' if individuals are alike in other ways, e.g. a need for dominance. Such a relationship may lead to conflict and disruption in the team.

Perhaps the most widely known theory that stresses differences rather than similarities as a basis for interpersonal attraction is the theory of complementary needs proposed by Winch (1958). A relationship will be 'complementary' if individuals having different but mutually-supporting personality characteristics are compatible, e.g. a person with a need for submissiveness will be compatible with another who has a need for dominance.

In his review of group composition studies, Haythorn (1968) cites numerous findings where either homogeneity or heterogeneity has been found desirable for superior team performance. Havron, Fay and McGrath (1952), for example, found that infantry rifle squads tended to perform better if members were similar in levels of aspiration, physical prowess, time in the army, and amount of combat time, while Adams (1953) found status congruency to be a contributor to effective bomber crews. Exline and Ziller (1959) also found that status congruent groups had less interpersonal conflict. In contrast to these findings, Hoffman and Maier (1961) found that problem-solving groups heterogeneous, according to scores on the Guilford-Zimmerman Temperament Survey, produced a higher proportion of high quality solutions than homogeneous groups. Similar results on a creativity task were found by Triandis, Hall and Ewen (1965) where attitude heterogeneity was conducive to performance. However, these groups were homogeneous with regard to abilities.

Such conflicting results have led to later work in this area to consider task variables. Tuckman (1967), for example, compared teams of different degrees of heterogeneity (concrete/abstract) on structured and unstructured tasks. Group performance differed as a function of the interaction between group composition and type of task. It appears that heterogeneity and homogeneity differ in their effects according to the characteristics and type of task to be performed. One can hypothesize, for example, that attitude heterogeneity is beneficial to problem-solving tasks because it enables numerous perspectives and alternative ideas to be put forward. This idea has been tested successfully in the management team-building area, notably by Belbin and his associates at the Industrial Training Research Unit, Cambridge, (Jay, 1980). Homogeneity, on the other hand, may limit such factors and so reduce group performance. Indeterminacy in the system environment would appear to require heterogeneity of team members whilst in a determined environment, or when non-cognitive tasks are performed, co-ordination may be enhanced by a homogeneity of attributes.

CHAPTER 2. PREVIOUS RESEARCH ON TEAM ORGANISATION

2.0

INTRODUCTION

There has been only a small amount of research on team processes reported in the literature. Indeed, most of this work has been concerned with aspects of team training (for reviews of team training research see Hall and Rizzo, 1975, and Wagner, Hibbits and Rosenblatt, 1977) with an emphasis on training in communications and an interest in whether teams perform more effectively when members have been trained individually or together as a team. When such studies have some relevance to team organisation, they have been included in this chapter.

Other work is described which has been carried out on unitary tasks. Of primary interest in these studies has been the mode of combination of operator responses and whether a division of responsibilities is more effective than shared, or redundant operation. Because each operator is capable of performing the whole task, and a genuine division of labour is not required, such work is of only peripheral interest to this study. On the other hand, there have been several studies performed on divisible tasks but most of these have been concerned with the effects of interaction among team members organised in a horizontal manner. Interaction has been studied at the input stage, where information is dispersed among team members, and at the output stage where operators are required to co-ordinate their responses to produce a single team output.

Only one study has been found which attempts to compare the performances of vertical and horizontal team organisations under different task demands. This work, by Lanzetta and Roby (1956 (b)) is described in detail since it provides a suitable basis for the experimental programme to be described in Chapter 3.

2.1

TEAM ORGANISATION WITH UNITARY TASKS

Using their reinforcement team task, Klaus and Glaser (1968) have examined the role of reinforcement in team operations. Two team members (monitors) made choice reaction time responses by depressing a key for either 2 or 4 seconds duration, depending on the visual input signal. A third team member (operator) observed the duration of these responses as indicated by lights activated by the key presses of the monitors. If the operator judged the responses to be of the correct duration, he depressed a key for 4 seconds, but if the response was judged incorrect, he made a 2-second response. The fourth experiment in the series studied the effects of team arrangement of two-man teams in relation to the accuracy of team performance (Egerman, 1966). Team performance was compared in three different structures; (i) series - where both team members had to perform adequately in order to complete the task successfully; (ii) parallel disjunctive - where success was achieved if either man performed adequately regardless of the performance of his partner, and; (iii) individual - where only the performance of one individual influenced team output, the performance of the other member never being considered. If team member A has a probability of correct performance of 0.62 and team member B a probability of 0.53 then, in a serial arrangement, the probability of correct team output will be a multiplicative function, $p = f\ (0.62 \times 0.53)$, equal to 0.33, whilst with a parallel structure, correct team output is described by the addition theorem, $p = 0.62 + 0.53 - (0.62 \times 0.53)$, equal to 0.82. In the individual arrangement, team output would be 0.62 or 0.53 depending on the member selected. When team performance was predicted by including member proficiency levels into the appropriate probability equation, predictions correlated 0.73 with actual performance, with the best performance by parallel teams followed by individual and serial teams in that order. Similar results were found by Zajonc and Taylor (1963) who demonstrated that in a series-type reaction time task, the team was less likely to accomplish its task as more series members were incorporated into the crew. Such performance prediction is usually achievable only for simple unitary tasks. However, depending on the output criterion adopted, a parallel team may not always be superior. This can be demonstrated by a number of studies performed on response combination using vigilance tasks.

Wiener (1964) compared the vigilance performance of two-man groups working together as a team, using a single display and a single response switch, with that of isolated operators whose outputs were combined and treated statistically as a team, i.e. a parallel switching circuit, where it was sufficient for either 'team' member to respond. Isolated monitors made more correct detections than those working together in series, but their false alarm rate was far higher. A system in which commissive errors were costly would suffer from such independence. Waag and Halcomb (1972) found similar results when they used simulated teams on a vigilance task. Subjects performed the monitoring task individually and teams were created through the use of computer-generated random numbers. Team performance was based on some combination of the responses of individual monitors through the application of 'decision rules'. Under a parallel decision rule, a 'team' response occurred if any one or more individuals responded whilst with a series decision rule, all members had to respond for a team response to occur. When two or more members were required to respond, detection performance deteriorated but false alarms were virtually eliminated. A reduction in false alarms at the expense of the percentage of items detected was also found by Konz and Osman (1977) when they used a series rule on their redundant inspection task.

All the above studies have been concerned with the method of combining responses of operators who have been working in simulated horizontal team organisations, but a study by Doten et al. (1968) specifically investigated team performance in a vertical organisation (see Fig. 1.4.1), where a second operator was required to check outputs from the first. Whilst independent working, as in the above examples, gave faster image interpretation than vertically organised teams, the level of accuracy was not as high. Consequently, the authors were interested in how the performance times of the latter could be improved whilst maintaining the accuracy and completeness of information extracted. Superior performance occurred when the checker had the most knowledge of the work of the initial interpreter, and this was more so when only those interpretations with a confidence rating of 40% or less were checked. In a vertical organisation, then, it appears that response times can be lowered, and accuracy maintained with the reduction of unnecessary checking.

2.2

DIVISION OF RESPONSIBILITY

The optimum distribution of task responsibilities between operators in a multiman-machine system is crucial to the efficient functioning of that system. When the tasks to be performed are divisible, they must be allocated among the team operators in the most optimal way so that individual operators are neither overloaded nor underloaded. The division of responsibility should lead to a balancing of the load imposed on team members, as in a study by Kidd and Kinkade (1958). As one of their series of experiments using air traffic control simulators, they varied the level of aircraft monitoring required of the controller. If, on approach to landing, a pilot was given responsibility for details of approach path configuration, e.g. decisions concerning letdown and course and speed adjustments, and the controller retained his responsibility for conflict avoidance, system performance under both normal and emergency conditions was superior to when the controller had responsibility for all details of approach. Such a division of responsibilities is one where concurrent tasks are performed by a horizontal team organisation (see Fig. 1.4.3. page 27). However, such an arrangement would appear to be inappropriate in another example from air traffic control. Sperandio (1978) describes the division of responsibilities between the controller and his assistant. The former is concerned with the detection and resolution of collision courses with the latter performing secondary tasks - a system of two interconnected, compensating channels. Increases in the complexity imposed on the system, though, tend to make the subsidiary tasks more dependent on the central task. The controller becomes even more overloaded whilst the assistant becomes less efficient at a time when he is needed.

Lanzetta and Roby (1956b)have noted the 'paucity of research' on the nature of the distribution of task responsibilities, on what factors determine the superiority of one type of team organisation against another. Since that time, the situation has not changed, with investigations in the area still being concerned with tasks which do not demand the division of responsibilities between operators. The tasks employed have been of a unitary nature where any one person is capable of performing the whole task, i.e. no division of labour is actually required, and the main concern has been with whether there are any advantages to be gained from a division of responsibilities (see Fig. 1.4.4. page 28) rather than shared, or redundant, operation (see Fig. 1.4.1. page 24). Since such investigations are of peripheral interest to this study, several of the experiments will be described.

a) <u>Shared versus divided labour with unitary tasks</u>

Morrissette et al. (1975) compared the monitoring performances of two-man teams working in either a division of labour organisation or a redundancy organisation. In the former, each team member monitored two of four displays, with all displays being monitored by both team members independently in the latter. The reduction in the number of displays to be monitored by each team member under the division of labour organisation resulted in a reduction in average performance time, but the back-up capability provided by a redundancy organisation eliminated long response times, thereby reducing performance variability. Team performance in the latter reflected the best performance of both team members. However, it was expected that team redundancy would not be as effective as a division of labour for critical signals of low intensity or for critical signals with several levels of intensity because of the slower scan rate required for signal detection with that organisation.

On a very easy task, it appears that the necessity for redundancy disappears since the probability of an individual failing, or making an error, approaches zero. However, Shiflett (1972) found a shared labour (or redundancy) organisation to be more effective than a divided labour arrangement on both an easy and a difficult task. Divided labour groups solved crossword puzzles in which one member had only vertical definitions, the other only horizontal definitions. The two members were not allowed to discuss their definitions with each other. The inferior performance of this organisation was attributed to the manner in which labour was divided, since if one member made an error it became more difficult for the other to fill in his adjoining words, and the restriction on communication made it difficult for members to locate an error. They had no way of determining whether an error had been made on the basis of their own performance. Shiflett (1973) felt that a more appropriate division of labour, which would eliminate these problems, would be to allow each member to work on one intact half of the puzzle. Results were ambiguous, with shared labour being more effective on the easy task than on the difficult one. Shiflett (1973) proposed a curvilinear relationship between organisation and task difficulty in which redundancy is of little value at the very easy and very difficult levels, while at the intermediate levels, redundancy was a major factor in increasing performance. Anyone working alone could perform well at the easy level whilst at the high level, it is the ability of team members which is lacking. Their mode of organisation is immaterial.

A further study by Roby (1967) tested three modes of organisation on three different vigilance tasks, each one containing four critical signal categories. In the homogeneous arrangement, each of four operators was responsible for all signals, two signals were assigned to each pair of operators in the paired arrangement, and in the individual arrangement, each signal was assigned to a different operator. Vigilance performance was generally superior in the paired structure and there was some interaction between team structure and the different types of task, e.g. code patterns in auditory messages, nonsense words scrambled in a letter matrix.

Studies such as those outlined above are of little use in deciding how task allocations should be made in the complex, interacting environment of the multiman-machine system. However, in spite of their simplicity or abstract nature, they do indicate that the organisation of the team is more or less effective depending on the characteristics of the task to be performed.

b) <u>Vertical and horizontal team organisation - a comparison</u>

Lanzetta and Roby (1956 (b)) investigated the relationship between two methods of work distribution and team performance under two levels of task complexity. They used a simulation of an air defence centre where the total complexity of tasks to be performed was such that a division of labour between operators was demanded. Unlike the tasks used in the studies described previously, it was impossible to perform the tasks in a redundant, or shared, manner without imposing a severe overload on the operator and a consequent breakdown in the functioning of the system. The authors were interested in how the effectiveness of a particular method of dividing responsibilities, i.e. of organising the team, would vary with changes in task characteristics. Using a board with a 50 by 40 grid identified by co-ordinates, three-man teams had to defend three target areas near the centre of the board by deploying an interceptor force of aircraft from three bases against an attack by enemy aircraft. An interceptor destroyed an enemy aircraft by landing on the square occupied by that aircraft, and vice-versa. Subjects were given information on the movements of enemy aircraft, flight plans for friendly aircraft crossing the board, and time signals indicating intervals during which interceptors could be moved.

In the vertical organisation, one operator monitored the position report and made the necessary moves on the board. The second operator was responsible for identifying aircraft to determine if they were friendly or enemy, and the third made all decisions concerning deployment of the interceptor force. Each team member in the horizontal organisation was assigned the responsibility of defending one of the three target areas with one-third of the interceptor aircraft. Thus, each operator had to monitor position reports, identify aircraft in his area, and deploy interceptors. The two modes of team organisation employed would fit the model shown in Fig. 1.4.2. page 26 . In the high complexity condition, fifteen aircraft were employed (nine enemy, six friendly) with ten at low complexity (six enemy, four friendly). Although the complexity x organisation interaction was not significant, there was a tendency for the horizontal organisation to be superior at low levels of complexity with the vertical structure superior at high complexity. Specialisation appeared to be relatively more effective when task load was heavy.

In analysing these results in terms of the characteristics of the tasks, Lanzetta and Roby felt that the inferior horizontal performance was mainly due to time-sharing problems encountered by operators. The tracking and plotting task was relatively more complex than the identification and deployment tasks and operators tended to 'fixate' on this to the exclusion of the other equally important task activities.

Other comparisons of this type are lacking, but one example was found where Green (1963) divided detection and tracking tasks between two operators at an expanded PPI display. The horizontal mode of division was found to be better when operators were 'sufficiently intelligent to take advantage of its flexibility', The author also suggested that face-to-face communication was important for the successful operation of a horizontal system. No attempt was made to interpret the findings in terms of the task demands imposed on the operators.

c) Procedural flexibility

A multiman-machine system may be permitted to modify its operating procedures to adapt to variations in load imposed on the system. This will be possible, and necessary, if the system environment is indeterminate, with uncertainty of inputs and a variety of available alternatives for action. In the Systems Research Laboratory Air Defence Experiments, the adaptation of a team to an increase in task or input complexity was studied. Chapman et al., (1959) found that teams experienced 'failure stress', arising from the disparity between aspiration and performance, and 'discomfort stress', arising from the difference between the effort demanded by the task and that which could comfortably be afforded. The former leads to discrimination in the relative importance of task components and leads to short-cuts and omissions, whilst the latter guides the selection of appropriate procedures. The development of new procedures by teams which resulted in increased system proficiency was also found by Alexander, Kepner and Tregoe (1962). Sweetland and Haythorn (1961) also found that as load was increased on team operators, there was a decrease in the time spent in processing each critical stimulus and a considerable decrease in the proportion of non-critical stimuli processed. Whether this was due to the impact of load or to the increased experience of operators was not certain. Another example of work performed in this series of studies, by Alexander and Cooperbrand (1964), examined the effect of strict versus flexible operating rules on a simulated air traffic control system with load held constant. In the strict rules condition, the team had to control the aircraft through all points along the complete route specified in the flight plan, whilst flight plans in the flexible condition contained only entry and exit points. Even with constant load, the change to more flexible rules produced significant changes in performance. Similarly, Johnston and Briggs (1968) found advantages from flexibility in their air traffic control task. When teams of two operators were able to compensate for early or late arrivals of aircraft under the control of their partner, they developed procedures which enabled them to perform under high load better than teams where such compensation was not allowed. In a study by Kidd and Hooper (1959) air traffic controllers operated under no restraint, partial restraint, or complete restraint conditions. Under partial restraint, handoffs between controllers could only be made within twenty miles of the airport, but no handoffs were permitted with complete restraint. However, the superior performance resulted in the no restraint condition where controllers were allowed to handoff if, and when, they desired.

Some degree of procedural flexibility is undoubtedly desirable in the multiman-machine system, and the extent of this must be considered when deciding on matters of team organisation. Flexibility would appear to be required both within - and between - team organisations. Whilst a certain type of organisation may be more appropriate to cope with a certain type of load on the system, that load may change over time, and an alternative organisation may then be more appropriate to cope with it. Therefore, rather than a team being organised in a rigid horizontal or vertical manner, provision should be made for alternating between the two. This is becoming increasingly possible in computer-assisted systems where advances in software allow more flexibility in team organisation.

2.3
INTERACTION BETWEEN TEAM MEMBERS

When teams are organised in a vertical manner, input information to the system is directed to the first operator who then performs his function before producing an output to the second operator. Interaction is therefore an integral and unavoidable part of the vertical organisation. However, when teams are organised horizontally, there are many variations on the possible modes of interaction between operators. It may be possible for tasks to be performed with no interaction between operators. Alternatively, operators may not have all their required information directly available to them. Such a situation would be probable in, say, a computerised command-and-control system where operators are performing different tasks in a concurrent manner. Because of the many sensing devices and possible dependency relationships between tasks, operators may have to interact with several others to acquire relevant information. Interaction would then be at the input level. If a single team output is required, operators will have to co-ordinate their responses in which case interaction will take place at the output level. (See Chapter 1.4. page 22 for a full description of the interaction possibilities in horizontal team organisations.) One can hypothesize that when interactions are required, system performance will be affected by such factors as the volume of information transmitted, the extent to which relevant information is dispersed throughout the team, and the nature of the communication structure available for information transmission.

Interaction between team members has been studied extensively, following the earliest work by Bavelas (1950) on communication networks. Interactions at the input and output stages have been investigated, as well as such topics as the effects of non-task-relevant interaction, the best methods of communicating information (verbal/visual), and the effects on performance of variations in the volume and content of communications.

a) Communication networks

The earliest laboratory studies on interaction in small teams investigated the effects of the communication structure, a set of positions with specified two-way communication channels. Bavelas (1950) asked whether some communications patterns may have structural properties that limited team performance. It may be, he felt, that 'among several communication patterns, all logically adequate for the successful completion of a specified task, one gives significantly better performance than another'. He introduced the concepts of links and distances between team members, as well as an index of the relative centrality of certain positions. To illustrate, Fig. 2.3.1. shows four basic communication patterns, or links, between five individuals: circle, chain, Y and wheel.

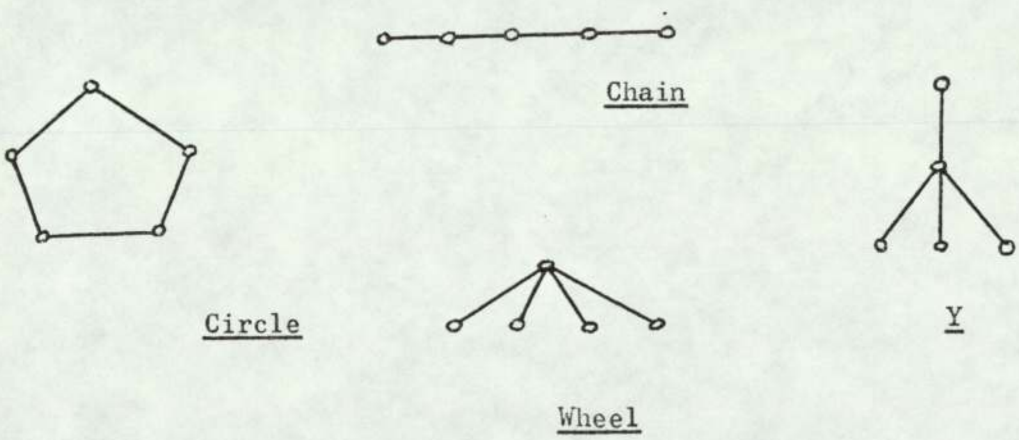


Fig. 2.3.1: Illustrative communication patterns among five individuals

For example, in the 'circle', an individual can communicate with two others in the group directly without relaying the message through some other person whilst, in the 'Y', one person in a central position can communicate directly with all the others. In the 'chain', two of the individuals must relay messages through three others in order to communicate. The 'distance' between positions varies inversely with the ease of direct communication between them. From these first formulations of Bavelas, many laboratory studies followed (described in Glanzer and Glaser, 1961) in which different structures were imposed on groups to study their effects on performance. Problem-solving tasks have usually been employed, with the trading of information among team members until each man knew the unique information given to other members of the group. One of the key dependent variables was the efficiency of the group, measured in terms of number of errors, correct completions, speed of solution, and number of messages transmitted.

These studies have shown that no network is best in all situations, the efficiency of the structure depending on the characteristics of the task. When subjects had to reconstruct a master list of words on the basis of incomplete lists, Heise and Miller (1951) found the 'circle' structure, where all members talked and listened to all members, to be most efficient. However, in a second task, in which subjects had to reconstruct a sentence based on parts given to each of them, the 'chain' with its central position, proved most efficient. Shaw (1954) also investigated the effects of problem complexity on different networks, hypothesising that 'a communication net in which all subjects are in equal positions (the circle) will require less time to solve relatively complex problems but more time to solve relatively simple problems than will a communication net in which one subject is placed in a central position (e.g. wheel)'.

Results from an arithmetical problem task supported this prediction but were not significant. However, a later study by Faucheux and Mackenzie (1966), using communication as a dependent variable, lent support to Shaw when groups working on a routine, deductive task developed more centralized communication structures than those working on a non-routine task with inferential elements. Behan (1961) has also demonstrated how an operator in a central position may become overloaded as problem complexity increases. It appears that the extra communication requirements in an 'all channel' network may counteract this tendency.

In further studies, Shaw (1956) also considered the distribution of information on the behaviour of networks, where each team member held some of the necessary information to solve an arithmetic problem. He compared a systematic - each member has all the information necessary to complete one step of an arithmetic problem - with a random distribution of information - a member had to approach several members for the information to complete one step of the problem. Results partly supported his prediction that systematic distribution would increase efficiency, especially if the network permitted freedom of action - 'circle' as compared to 'wheel'.

It is generally agreed (Meister, 1976; Glanzer and Glaser, 1961) that the network studies have not succeeded in answering the question posed by Bavelas. This is due to two main reasons: the effects of task characteristics and the nature of the experimental tasks. The effect of structure depends to a great extent on the requirements of the task so that, for example, a highly centralised structure may be more efficient for certain types of task and a decentralised network more efficient for others. The experimental simplicity of the network task - network members communicating via written messages through slots in the cubicle walls separating them (nets were created by closing the appropriate slots) - had little relevance to real-life situations. Because of the many factors influencing communications in multiman-machine systems, results from the network studies have little applicability.

b) <u>Interaction at the input level - Dispersal of information</u>

A series of experiments concerned with the dispersal of information among team members has been performed by Lanzetta and Roby. Their first study (Roby and Lanzetta, 1956) imposed four different communication structures on three-man groups. All members had identical task requirements, the structures differing only in the proportion of information which had to be transmitted and in the extent to which relevant information was dispersed over team members. Performance of the team was related to both these factors. If relevant information was directly available, or if it could be relayed from a single source, performance was superior to that when information had to be obtained from several sources. A second study (Lanzetta and Roby, 1956(a)) extended the above investigation to consider the effects of varying both the rate of change of inputs and the predictability of the order of presentation to the three team members. Again using their simulation of a bomber crew task, subjects sitting in separate booths were required to observe two displays and to set two switches periodically depending on the inputs. In the low autonomy (high interaction) condition, operators had to obtain four information units from external sources, while high autonomy (low interaction) required each subject to obtain only one unit from other operators. As in their previous study, the most difficult structure was one where a larger proportion of information had to be relayed, and when this had to be relayed from several sources. Errors for both structures increased when the rate of change of inputs was increased, but predictability had no effect.

The next study in the series (Lanzetta and Roby, 1957) utilised two operating procedures: (i) team members were encouraged to 'volunteer' information they knew was required by other team members and; (ii) no 'volunteering' was permitted, with members only being able to respond when 'solicited'. However, there was no differential effect on performance between the two procedures. Again, rate of input changes and degree of autonomy significantly influenced team performance with the high autonomy teams making less errors. Additional measures were taken of the number of messages transmitted, the average length of messages, and the total time spent in communicating. When interaction requirements were high, more time ($1\frac{1}{2} : 1$) was spent in communicating, as would be expected, but approximately four times as much information had to be transmitted than in the high autonomy condition. Thus, relative to the demands of the structure, information transmission is greater in the high autonomy condition. The authors felt that this redundancy in messages may be due, for example, to unnecessary checking between operators or to irrelevant communication, concluding that 'under constant situational pressures, groups modify their behaviour at a characteristic rate which is independent of the demands placed on them'.

In general, these studies have shown that, other things being equal, the more autonomy attaching to display-control actions, the better is the performance obtained. However, in the last of their experiments, Roby and Lanzetta (1957) acknowledge the fact that if operators have too much autonomy, a load imbalance on the system may arise. To illustrate the conflict between independence and load balancing, an experiment was performed in which the information from six displays was processed by the use of six controls. Certain display information was required for certain control actions, but controls and displays were assigned to different operators in the team. When an operator did not have the necessary display information for his control action, he had to interact with the appropriate operator. In the first condition, displays were equally divided between the three operators: more displays were assigned to the operator with most control responsibility in the second; and the third condition counterbalanced control responsibility by assigning the most displays to the operator with the least controls. In terms of interactions, the first two conditions were equal with more interactions required in the third condition. The best performance was achieved by the first condition (low interaction: medium load imbalance) followed by the second (low interaction: high load imbalance) and worst in the third (high interaction: low load imbalance). Both independence and load balancing, then, exerted significant effects on team performance.

c) Interaction at the output level - the co-ordination of responses

A series of studies by Briggs and his co-workers at Ohio State University (summarised in Briggs and Johnston, 1967), although more concerned with team training, varied the interaction requirements of two-man, horizontally-organised teams at the output level. An aerial intercept task was used where controllers were required to issue verbal commands to 'interceptor pilots' on the basis of visual information from simulated radar displays showing the positions of target and interceptor aircraft. Commands were made over radio-voice channels to the 'pilots' and the team attempted to position the interceptors within a minimal distance from the target before relinquishing radar control. In their first experiment (Naylor and Briggs, 1965) controllers either worked independently from each other or, in the interaction condition, they could interact over a voice channel to discuss the movements of interceptors and targets. Interaction was not necessary between operators. Occasional interaction was desirable, though again not necessary, in the second experiment, (Briggs and Naylor, 1965) when targets crossed from the zone of responsibility of one operator into that of the other. In both studies, superior performance was achieved by those teams where controllers had acted individually, i.e. without interacting.

A later experiment in the series (Experiment 5: Johnston, 1966) increased the need for co-ordination by requiring the simultaneous interception of a target by two interceptors. When such co-ordination was within-individual, i.e. one team member controlled both interceptors, performance was superior to when co-ordination was between-individuals, i.e. each team member controlled one of the two interceptors. A high incidence of irrelevant information transmission was noted in the latter case, and operators would often seek information from their partner when it could have been more easily obtained from their display. Similarly, Jensen (1962) compared teams performing a tracking task under conditions of restricted communication (each member worked in a separate booth with no opportunity to interact), or in a free communication situation. It was thought that the latter condition would permit teams to utilise verbal communication to help each other and to organise their work more effectively. Again, though, any benefits arising from interaction tended to be outweighed by interference from non-task behaviours.

Related research showing the disruptive effect of verbal communication has been performed in the vigilance area in studies of paired as opposed to individual monitoring. From the 'activation' interpretation of vigilance behaviour proposed by Deese (1955), it was felt that individual monitoring would be facilitated by the background sensory input provided by the presence of other monitors. Bergum and Lehr (1962) failed to support this hypothesis, but did find significant relationships between the individual performance of paired individuals and the amount and intensity of conversation between them. They suggested that the effects of background stimulation may be dependent on the degree of that stimulation. A relatively low level may be facilitative, but a high level may be distractive and interfere with performance.

This theme was elaborated upon in another experiment in the Ohio series (Experiment 7: Williges, Johnston and Briggs, 1966) when two-man teams performing the simultaneous intercept task were trained and then tested under alternative information channel conditions. Teams were trained under either a verbal-visual condition (Ve-Vi) or a verbal condition (Ve). In the former, a controller could obtain co-ordination information from his partner either verbally or through inspection of a display, whilst verbal communication was necessary in the latter since a controller had a visual display showing only his own zone of responsibility. Teams then transferred to Ve or Ve-Vi conditions. Performance was superior in the Ve-Vi transfer condition regardless of whether teams had been trained under Ve or Ve-Vi conditions. The results suggest that the superiority of a visual channel is not a matter of training alone but is inherent in the nature of the channel.

d) Volume and pattern of verbal communication - the effects on team performance

Whilst the interference effects of verbal communication, and its inferiority to visual methods of conveying information, are well-documented in the literature, verbal communication is nevertheless unavoidable in the majority of multiman-machine systems. Consequently, efforts have been directed to determine whether there are any relationships between the volume and pattern of this communication and the performance of the team. An overview of the various taxonomies of verbal communication developed by investigators in this area is given in Chapter 1.4. page 29. Attempts have been made to perform content analyses of communications to find variables that correlate with team performance. Alternatively, teams have been trained in those communications thought to be required for team performance to determine whether performance improves as a result of the training.

Krumm and Farina (1962) studied four-man teams on simulated B-52 missions. They found that increasing experience in team exercises was accompanied by an increase in the number of voluntary messages. Since these messages revealed such factors as an alertness to the needs of others and a readiness to assist, the authors suggested that such messages were an index of the degree of co-ordination between team members. However, the pattern of communication appeared to differ between teams engaging in a high volume of communication and those that transmitted relatively few messages. Low volume teams emitted a high proportion of voluntary messages, but a low proportion of questions and answers. The opposite was true for high volume teams. This, again, was interpreted as indicative of co-ordinative behaviour, since inefficient questions and answers are unnecessary if team members have learned to anticipate the needs of others.

A study by Federman and Siegel (1965) used simulated three-man helicopter crews on simulated ASW missions and found that at mission phases in which uncertainty is greatest, communications volume is increased to reduce the uncertainty and develop a course of action. When the uncertainty is reduced through evaluation of the situation, the volume is reduced. However, only two of twenty-six content categories were significantly correlated with team performance. Better teams utilised more non-risk than risk communications, and they provided more information messages.

Analyses of communications were also made in the afore-mentioned Ohio series of studies (Briggs and Johnston, 1967). They found that under time stress, teams communicated less and restricted messages to objective data. However, the relationship between communications variables and team performance showed few significant correlations and these were often negative.

The various studies cited do indicate that there is some relationship between communication variables and team performance, but the failure of investigators to find significant aspects of this relationship again questions the value of inter-operator verbal interaction.

2.4

COMPUTER MODELLING OF THE MULTIMAN-MACHINE SYSTEM

Siegel and Wolf (1969) have developed a model based on the use of a digital computer which aims to simulate one- or two-man machine systems. From an analysis of the man-machine system and the task under consideration, the various sub-tasks to be performed, and the procedures to be followed are determined. Thereafter, 'input data' relating to such factors as the average sub-task execution time, the probability of success, the relative importance of sub-task completion, and waiting time are found. The other data required by the computer in advance of the simulation are the 'parameters' and 'initial conditions'. Included among the former are assessments of the stress thresholds for each operator, the total time allotted to each operator for task completion and individuality factors which attempt to account for variance among individuals. The computer then sequentially simulates, according to the rules of the model, the 'performance' of each sub-task by each operator. Results are recorded to indicate areas of operator overload, failure, peak stress and so on for the selected parameters. Repetitions of the simulation, using different parameter values enable the preparation of possible levels of performance.

From this early work has grown a number of techniques aimed at estimating the mission performance of a complete system, e.g. Human Operator Simulator (Streib, Glenn and Wherry, 1980) and SAINT (Chubb, 1980). All make basic assumptions about the human operator. Among these are that the behaviour of a trained operator within a defined system is predictable and goal-oriented, human behaviour can be described as a series of 'micro-events' (e.g. information absorption, recall of information, mental calculation, decision-making) which can be aggregated to explain task performance, humans have a single channel for input and output and a single 'information processor', and trained operators rarely make errors or forget their procedures. As Siegel and Wolf (1969) described their own model, they depend on a 'rational and synthetic logic'.

Although such techniques are still in their infancy, they do seem to be useful in predicting the performance of individual operators on relatively simple tasks, but their value has yet to be proved in a complex multiman situation when a high amount of interaction takes place between operators and/or the system environment is of an indeterminate nature. Mathematical models of multiman-machine systems are, as yet, somewhat oversimplified and appear unable to adequately represent the dynamic and adaptive behaviour of the human being in a complex system.

2.5 TASK CHARACTERISTICS AND TEAM ORGANISATION

Since Lanzetta and Roby (1956 (b)) noted the 'paucity of research' on the nature of the distribution of task responsibilities between team members, the situation does not appear to have changed. Investigations, concerned with such factors as shared as opposed to divided labour, have used unitary tasks which do not require a genuine division of labour. Whilst such studies do indicate that the effectiveness of a particular team organisation appears to be dependent on the characteristics of tasks to be performed, the unitary tasks used are often simple and abstract and of little use in deciding on task allocation in complex, multiman-machine systems. The work performed on interaction between operators has been concerned solely with horizontally-organised operators. Although divisible tasks have been used in these studies, no comparisons have been made with a vertical method of team organisation. The main conclusions drawn from these studies are useful, though, because they demonstrate limits to the effectiveness of the horizontal organisation. For example, if interaction requirements are high at either the input or at the output level, team effectiveness is often lowered. However, too much autonomy of operators may lead to overload at high levels of task complexity.

The only study to compare the performance of horizontal and vertical team organisations on a divisible task and, at the same time, study these effects under different levels of task complexity was that by Lanzetta and Roby (1956 (b)). In analysing their results, the authors felt that the inferior performance of the horizontal organisation at high complexity was due to problems in time-sharing caused by the nature of the different tasks to be performed, i.e. they noted the probable dependency of their results on task characteristics.

The present programme of research aims to extend this type of study to compare the effectiveness of vertical and horizontal team organisations with a variety of task characteristics, and to specify more adequately the relationships between them.

3. EXPERIMENTAL WORK

3.0

INTRODUCTION

The following series of five experiments has been designed to investigate the effects of variations in task characteristics (complexity and organisation) on the performance of two-man teams organised in either a vertical (serial) or horizontal (parallel) manner. Experimental tasks have been used which attempt to represent as realistically as possible, in terms of their type and method of accomplishment, those commonly found in a wide variety of real-world command, control and communication systems. However, because of time constraints, it was necessary that experimental tasks did not require extensive training for adequate performance. As such, they may be described as system analogues, in which operators are required to produce a system output based on the processing of information from the system environment. By analysing aspects of team functioning in this way, it is hoped to develop some generalised principles on the design of jobs in such systems which will aid systems designers in the promotion of greater operational effectiveness in systems of the future.

a) Types of task and independent variables

Common to all tasks used are the functions of identification, plotting and reporting of tracks constructed from raw contact information. The first experiment uses a task modelled on the operational naval task of manual 'bearings-only analysis', which involves the identification and manual plotting of contact time and bearing information prior to the construction of a further plot, (local operations) and the reporting of track movements. Tasks must be performed sequentially with the latter task being dependent on the prior completion of the former. In the vertical team organisation, the first operator produces the time-bearing plot with the second being responsible for the local operations plot. Horizontal operators each perform both tasks but only for contacts appearing in their own areas of responsibility. Fig. 3.0.1. shows the team organisations used in the first experiment.

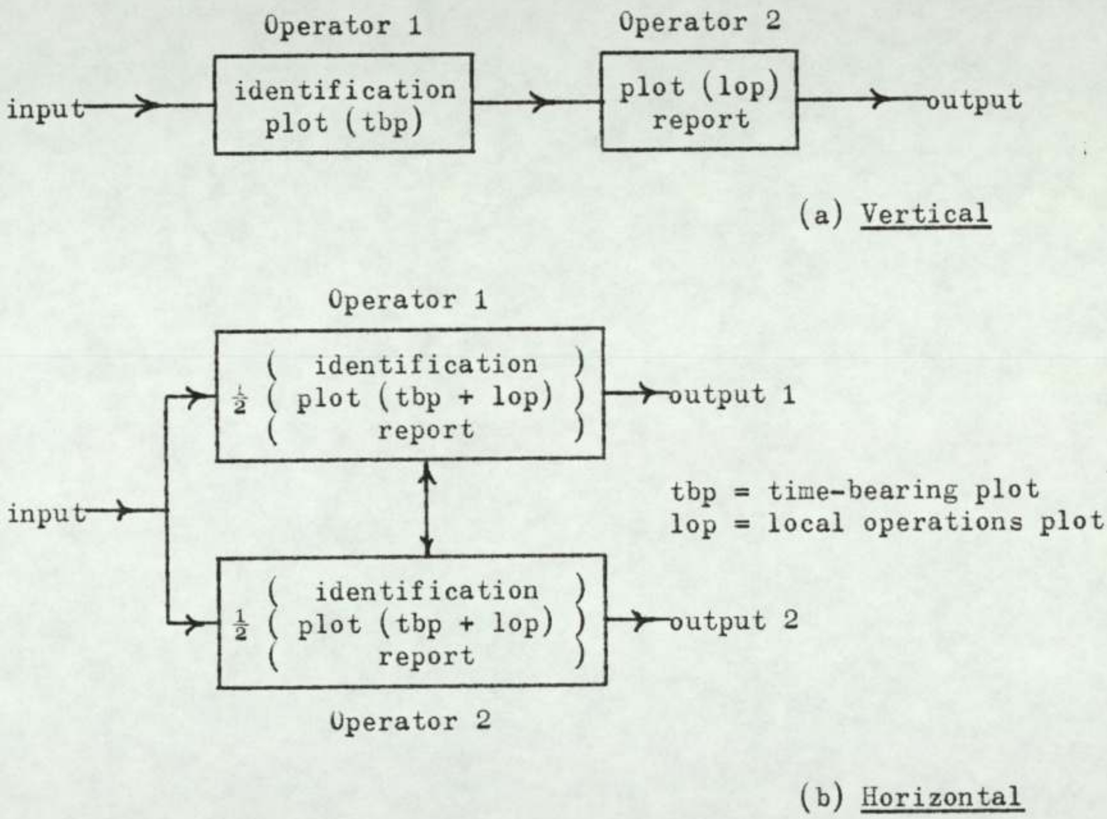
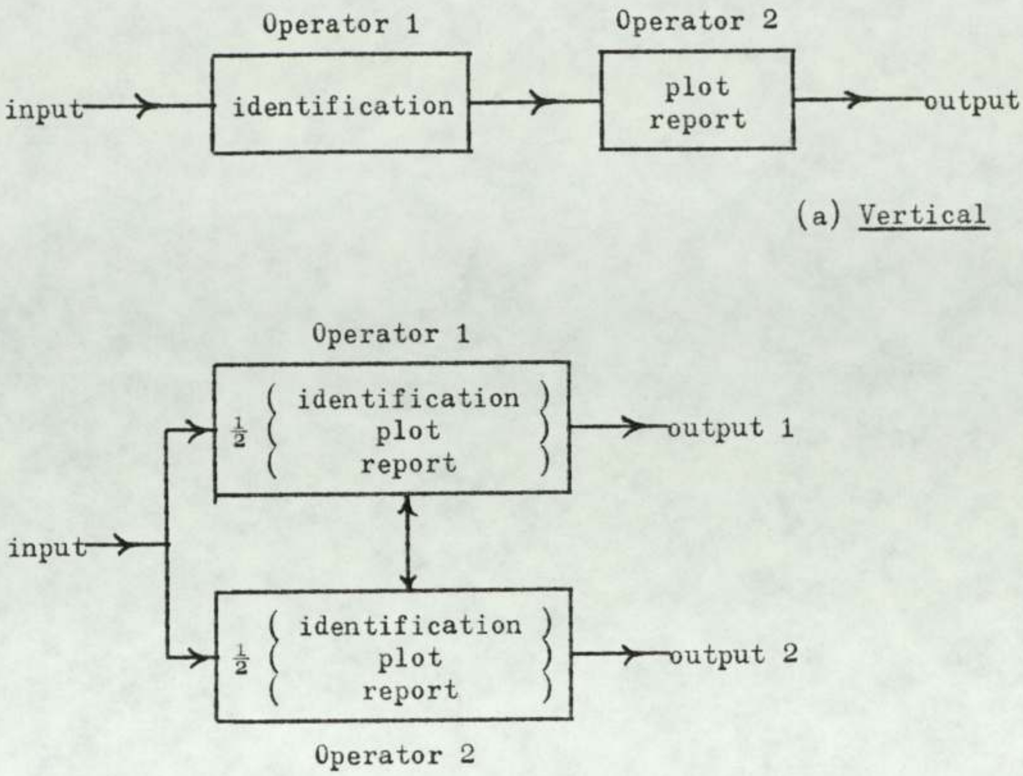


Fig. 3.0.1: Vertical and horizontal team organisations - Experiment 1

The vertical method of organisation produces a functional division of responsibilities, with the resulting precedence relationships established between operator positions calling for co-operation of a co-ordinative manner between team members. With the horizontal method of team organisation, each operator performs all tasks (identification, plot and report) but the total task complexity is shared. Any interaction, or co-operation, between team members in the horizontal team organisation is of a collaborative nature.

The final four experiments, where a simulation of a naval picture compilation task is used, are more representative of advanced systems, since computer-assistance is available to operators to aid them in their plotting and reporting tasks. A communications system was also constructed for use in these experiments to facilitate interaction between operators, in addition to making possible the recording of verbal reports. Here, the task allocation between the two operators organised vertically was different to that in the first experiment, with the first and second operators performing the identification and the plot and report tasks respectively. Horizontally-organised operators continued to perform all tasks for those contacts appearing in their own area of responsibility. Fig. 3.0.2. shows the team organisations used in the second, third and fourth experiments. The horizontal operators are able to interact if they wish but this is not necessary for successful completion of their tasks. Operators are able to work independently on separate items of information, although interaction is beneficial, particularly in the sorting of inputs. In the fourth experiment, interaction became necessary for effective horizontal team performance when tracks crossed between different areas of responsibility, and became a task requirement when status reports were required in the final experiment. The communication flow for that particular condition in the fifth experiment is shown in Fig. 3.0.3. Operators are no longer processing only independent, or different



(b) Horizontal

Fig. 3.0.2: Vertical and horizontal team organisations - Experiments 2, 3 and 4

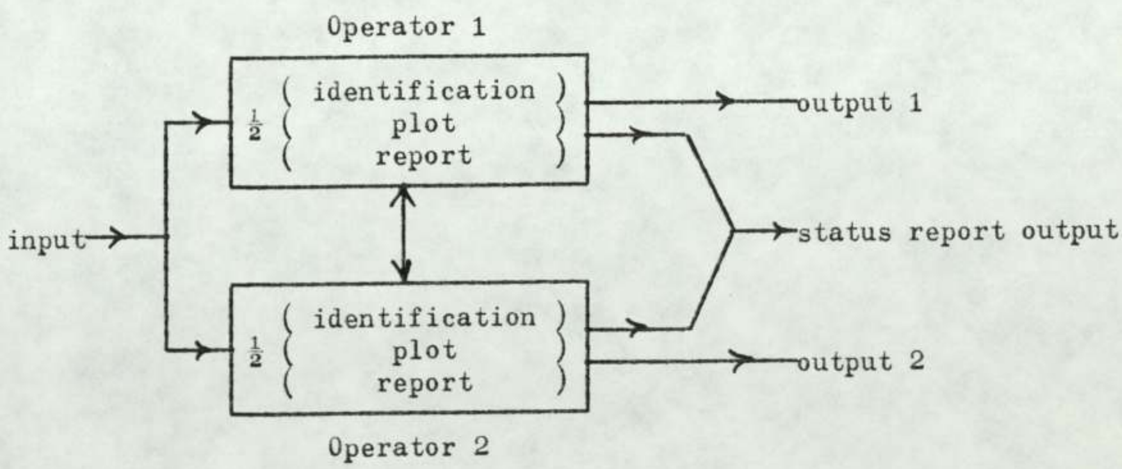


Fig. 3.0.3: Horizontal team organisation with partially-shared information - Experiment 5

information. They are sharing, or collaborating on, the processing of certain items of information to produce a single output.

The second independent variable, apart from the organisation of the team, throughout the five experiments, was the total complexity of tasks to be performed. This was varied as follows:-

Experiment 1 : presentation rate of contacts;

Experiment 2 : presentation rate of contacts;

Experiment 3 : number of alternative tracks;

Experiment 4 : increases in input complexity when tracks crossed between different areas of responsibility;

Experiment 5 : introduction of a concurrent task - the status report.

b) Input data

For each of the experiments, the desired inputs to the system were created by prior construction of the required scenario. For the first experiment, this involved the construction of the time-bearing plot on a similar sheet of graph paper to that used in the experiment. The required number of tracks was drawn and the required number of 'contact' points was entered. It was then a simple matter of noting the particular time and bearing associated with each contact. This data was then presented to subjects at the appropriate time. Input data for later experiments, when experimental runs were under program control throughout, was transferred from diagrammatic form (see Appendices III - VI for track formats) to the control program with the aid of two computer programs. One program (NAVTR) was used to calculate the co-ordinates of individual contacts, whilst the other (NAVDAT) was used to enter the desired time intervals between presentations of contacts to operators. The latter program then combined the 'interval' file and 'track' file to compile a third program (NAVAL) which determined the course of the experiment.

c) Dependent variables

A number of time and accuracy measures were taken, with an emphasis on the performance of the team, rather than on that of the individual team members. In the computer-controlled experiments, data was recorded on magnetic tape. A complete timed transcript of the interaction between computer and operators was available, together with the timing of significant events. The verbal reporting measures were not included since these were held on a tape recording, but a timing mark was displayed on the transcript, and recorded by the tape recorder whenever operators pressed the reporting button. It was then possible to associate the two marks to obtain data on reporting.

3.1

EXPERIMENT 1: The effect of input rate on team performance using a task with a high motor demand

There are a number of ways in which a team may respond to changes in the rate of inputs. The simplest way would be through changes in manning, but of main interest to this study is the way in which the original team can be organised differently to spread input comp. as evenly as possible among its members. Such a division of responsibilities may be along functional lines whereby the whole task is divided into functional categories and a function is assigned to each individual. Alternatively, the whole task may be divided so that each individual still performs the whole task, but the complexity is shared. If, for example, in a command, control and communication system there are detection and classification tasks performed by separate operators, there is a functional division. However, these two tasks could possibly be performed by both operators so that the two men share the total complexity e.g. one operator being responsible for contacts appearing between 0-180^{o}: the other for contacts between 181^{o}-360^{o}. The superiority of one method against the other would depend on the extent to which the speed and accuracy of task performance is improved.

Previous research in this and related areas (see Chapter 2: 'Research on Team Organisation' for a literature survey of the area) shows that both methods of division of responsibilities have their advantages. However, results do tend to be rather task-specific and it is therefore difficult to generalise any findings to all types of task.

The following experiment uses a task modelled on the operational naval task of manual 'bearings only analysis'. Operators construct plots from contact information, using pencil, paper, and various measuring instruments, in order to calculate the movements of other vessels in the area. As such, the whole task imposes a high degree of motor demands as well as various perceptual, information-processing, and communication activities.

Using the organisation of the team along 'vertical' (functional) or 'horizontal' lines, and the rate of presentation of contacts as the key independent variables, the experiment seeks to measure the effects of different input levels on team performance on a task of this type.

METHOD

a) Task and Apparatus

The experimental task used was an adaptation of the real-world task of manual 'bearings only analysis' (BOA). In the Operations Room of a submarine, the sonar sub-system is used to acquire data on the positions of other vessels in the surrounding area. However, the only information available from these contacts is the bearing of a vessel at a certain time. The bearing, alone, is of little use to the Command in determining an appropriate course of action: it is necessary to know the range, course and speed of that vessel. The first requirement is the construction of a time-bearing plot (TBP) on which all bearing data from the sonar (or sound) room is plotted against time. In this way, tracks can be constructed showing the progress of other vessels (see Figure 3.1.1). However, in order to calculate their range, course and speed, it is necessary to produce a further plot known as the local operations plot (LOP). Here, against the movements of 'own ship', are drawn bearing lines using bearing information made available at equal time intervals from the TBP (see Fig 3.1.2). The LOP operator then uses multi-point dividers to estimate equal distances between all bearing lines for each vessel being tracked. In this way, the course of a vessel can be estimated, and estimates of its range and speed can then be made. This information is continuously updated as more bearing information from TBP enables more bearing lines to be drawn on LOP. Predictions of future movements of vessels can also be provided to the Command for tactical appreciation. The whole process, known as 'picture compilation' is becoming increasingly computer-assisted, but manual BOA is still widely practised.

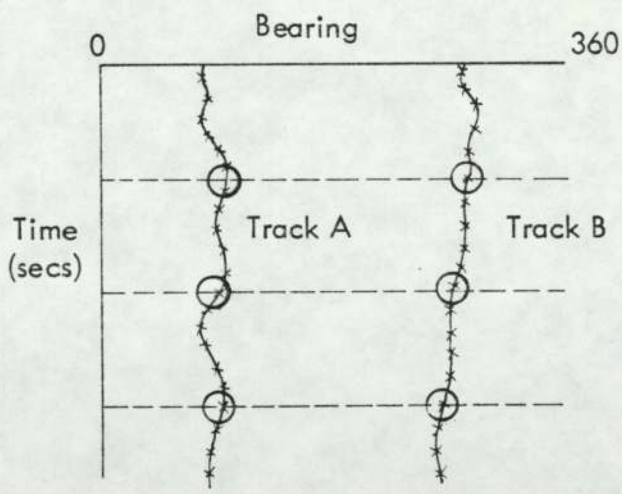


Fig 3.1.1

The Time-Bearing Plot

Depending on the condition to be tested, subjects were required to construct a TBP and/or the LOP for selected tracks. Sheets of 1mm graph paper were provided incorporating certain job aids. On the TBP were lines drawn at equal time intervals at which information was to be transferred to the LOP, whilst on the

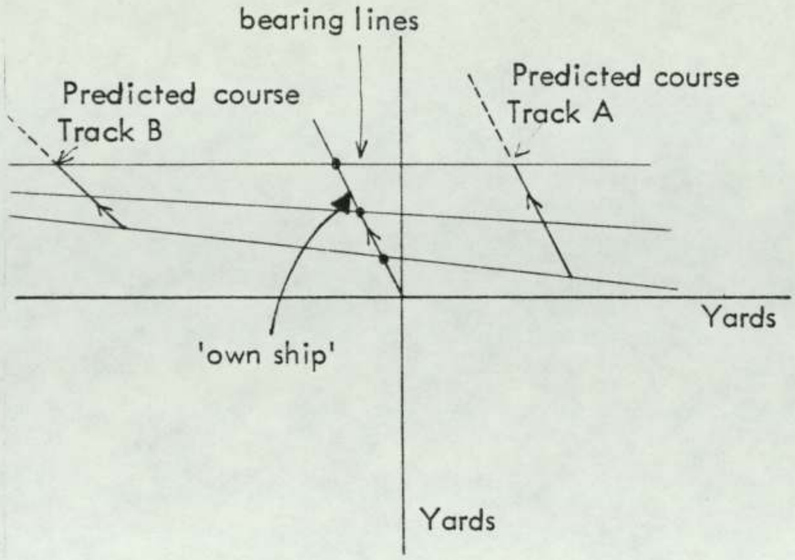


Fig 3.1.2

The Local

Operations Plot

LOP, the movements of the 'own ship' were represented along with the required time intervals, from where the bearing 'fan' was to be constructed. For the latter, a 360^{o} protractor was provided, with a pair of multi-point dividers to predict the range and course of the track. The input to the TBP from the sound room was simulated by the use of 5" x 3" cards on which were written a particular bearing and associated time. Input data, i.e. times and bearings, were produced from a time-bearing plot constructed by the experimenter. It was then possible to extract the required number of associated times and bearingsfor presentation to operators at the appropriate time intervals.

b) Subjects, Design and Procedure

The subjects were 24 undergraduate volunteers drawn from the student population at the University, who were paid for their services. All had no previous experience of naval tasks and none had served previously as a subject in a similar experiment. They were randomly assigned to experimental conditions.

The independent variables used were the organisation of the team and the **level of input complexity.**

(i) Organisation: two types of organisation were used: one based on a functional division of responsibilities known as 'vertical', and the other involving a division of the total * **comp.** so that each member of the team performs the whole function for his own tracks - a division of responsibilities along 'horizontal' lines. For example, with a vertical organisation, one operator would perform the TBP function and the second operator, using input from the first, would perform the LOP function. With a horizontal team organisation, each operator would perform both TBP and LOP functions for his own tracks.

(ii) **Comp:** two levels of **input** were used: a high level using four tracks and a low level using two tracks. In the half-hour experimental period, contacts were presented to the subject at 45-second intervals, i.e. 40 contacts per track. Thus **high complexity involved** the construction of TBP and LOP using information on 160 contacts; a low **comp.** the same for 80 contacts.

Four experimental conditions were formed from a factorial combination of the two types of team organisation and the two levels of complexity. Three teams were assigned to each condition. There was a prior training period of 30 minutes during which subjects were briefed as to the purpose of their task. Procedures to be followed were demonstrated and explained by the experimenter and questions were answered. A brief practice session followed with the team members performing all the necessary tasks. At this point, the experimenter emphasised the need to balance speed of performance against accuracy.

* N.B. In parts of the text, it has been necessary to reduce the word 'complexity' to its abbreviated form 'comp.'.

The four experimental conditions, shown below in Figure 3.1.3, were as follows:

(i) Vertical organisation: High comp:- one team member plotted the TBP from contact information on all four tracks - information was supplied directly by the experimenter on written cards. The other team member was solely responsible for constructing the LOP for all four tracks using written bearing information supplied from TBP at pre-determined 5 minute intervals. This information was used to draw the bearing 'fan'. When three and more bearing lines were available, the LOP operator then used multi-point dividers to provide estimates of the track's range, course and speed. Because of confusions among subjects with terminology, it was decided that it would be sufficient for the LOP operator to measure and record distance from 'own ship' to the predicted position of the vessel in question.

(ii) Vertical organisation: Low comp:- as in (i) but for two tracks instead of four, i.e. 80 contacts.

(iii) Horizontal organisation: High comp:- the four tracks were divided so that each team member constructed both TBP and LOP for two tracks. The experimenter provided each operator directly with information on his own tracks. As in (i) and (ii) bearing lines were drawn on LOP at 5 minute intervals from information on the TBP.

(iv) Horizontal organisation: Low comp:- as in (iii) but for two tracks only. Each team member was responsible for constructing TBP and LOP for one track.

Under each of the above conditions, the development of a 'backlog' of bearing information cards was permitted. However, at the time of transfer of information to LOP, any backlog of cards was removed by the experimenter, so that necessary information could be passed on at, or as near as possible to, the appointed time.

		Complexity	
		High	Low
Team Organisation	Vertical	$T_1 - T_3$	$T_7 - T_9$
	Horizontal	$T_4 - T_6$	$T_{10} - T_{12}$

Fig 3.1.3: Experimental Conditions (T denotes team)

c) Performance measures

The key accuracy measures in this study are the plotting errors made on the TBP, which arise in two ways: (i) any deviation from true bearing, and (ii) the number of omissions. These will be termed 'errors of commission' and 'errors of omission' respectively. Because of its predictive nature, the LOP does not lend itself to the provision of reliable performance scores, i.e. the use of multi-point dividers by inexperienced subjects on limited bearing information gives wildly varying estimates of range, often from the same information. The LOP, though, is necessary so that different aspects of time-sharing between the two sub-tasks by the vertical and horizontal methods of team organisation can be investigated.

It was hoped to obtain other data from the video-recording of experimental sessions. Of interest here are the amount and content of communications between team members. Differences in patterns and rates of work were also relevant.

Although no systematic interview or questionnaire was administered to subjects, verbal reports were obtained in a de-briefing period following the experimental session, when subjects were asked to describe their feelings about the task, how they felt it could be improved, events which had caused them particular difficulty, and so on.

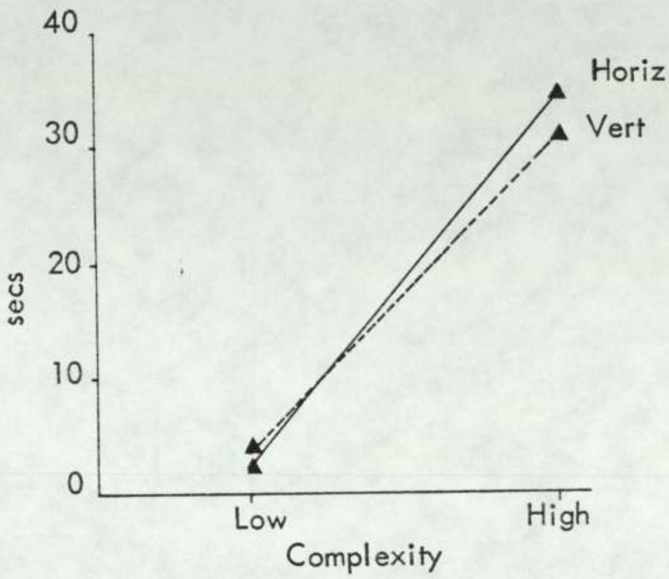


Fig 3.1.4
TBP Plotting
Errors

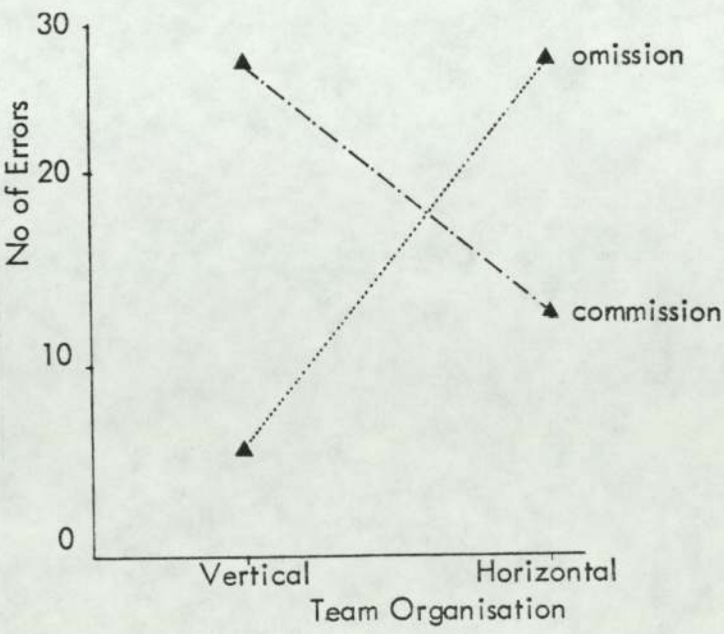


Fig 3.1.5
Plotting Errors
by Type - High
Complexity

RESULTS

a) TBP error scores

The amount of plotting error, shown in Fig. 3.1.4, made by teams organised in both vertical and horizontal modes increased significantly with the high comp condition, $F\ (1,8) = 460$, $p<0.01$, but no overall significant differences between types of organisation were found (see Appendix VII for all analyses of variance carried out on experimental data). At low comp, neither form of team organisation made any errors of omission, but, at high comp, it is interesting to note that errors of omission accounted for 70.1% of the total errors made by the horizontal organisation and for only 16.5% of total errors made by teams working in a vertical organisation. Fig. 3.1.5 shows the average amount of both types of error under high comp. An analysis of variance carried out on this data (see Appendix VII) shows that, whilst there are no significant differences between total errors of commission at this level, and between total errors of omission at this level, there is a significant difference, $F\ (1,8) = 29.82$, $p<0.01$, between the type of error and its occurrence under either vertical or horizontal team organisations. A simple main effects carried out on this data further shows that this effect is attributable to a significant difference between errors of commission made by vertical and horizontal teams, $F\ (1,8) = 9.11$, $p<0.05$, and a significant difference between errors of omission, $F\ (1,8) = 20.47$, $p<0.01$, made by each type of team organisation

b) Communication and Activity Patterns

(i) Communication: it is possible to perform both TBP and LOP operations with no verbal communication whatsoever, especially when, as in the study, TBP to LOP information flow is by written communication. This was found to be the case in the 'Vertical-High' condition where continuous working restricted the opportunity for even task-irrelevant communication. Both conditions using a horizontal team organisation were typified by little or no communication. Here, operators were completely autonomous, with all required information directly available to them. The two operators tended to work as individuals rather than together as a team. Communication was evident in the 'Vertical-Low' condition but this tended to be task-irrelevant, probably arising from boredom.

(ii) Activity: study of the video-recording also made possible a sample of activity in the last ten minutes of each experimental session. Under high complexity both operators in all teams were working for the full duration. However, at the low complexity there was considerable idle time with both types of team organisation. It is difficult to draw any conclusions since, whilst some operators would be working continuously throughout the sampling time, others performing the same function may be unoccupied for almost fifty percent of the time. This was evident under both types of team organisation and was probably due to the inexperience of the operators, e.g. checking work, making corrections and so on.

c) Verbal reports

If a repeated measures experimental design had been used, subjects would perhaps have been better able to comment through being in a position to compare one experimental condition with another. However, from comments received, it would appear that the 'wholeness', mainly in terms of task identity, of a horizontal team arrangement was preferred to the repetition typical of a functional division. However, many subjects spoke of being overloaded in the high comp conditions, particularly with the horizontal team organisation. Boredom was a frequent complaint from those who had worked in a low comp condition but this was more of a problem when the subject had been part of a vertical team organisation. In general, it seems that a horizontal arrangement was preferred, providing that the load is not excessive.

DISCUSSION

Although the effects of organisation were not significant, there was a tendency for a vertical arrangement to be superior at high comp. When load became stressful, subjects in different team arrangements tended to adopt different coping mechanisms. Vertical team members were usually able to catch up on any backlog of information and queuing was evident. When time sharing was required between TBP and LOP in the horizontal arrangement, catching up often became impossible and consequently the vast majority of errors were due to omissions. Operators in the latter concentrated on the critical bearing information required for transference to LOP. Such a strategy was possible in this particular task, but would be unacceptable when critical signals are arriving at irregular time intervals, or when updated information is required by the Command at any time.

Experienced personnel would probably have produced fewer errors, in particular the errors of omission. Although a speed/accuracy trade-off was stressed by the experimenter, many subjects tended to concentrate on accuracy at the expense of speed. This is shown in the videotape of the low input complexity conditions where some subjects appeared to be working continuously while others became bored from the lack of input.

The inferior performance of the horizontal organisation was due to overload at high levels of complexity. This was caused by the difficulties encountered in time-sharing between the time-bearing plot and the local operations plot. Construction of the latter was a particularly complex task due to the high degree of motor demands imposed on the subject, e.g. from the use of multi-point dividers, protractors, etc. Also, there was little, if any, intra-task organisation between this task and that of constructing the time-bearing plot. The ensuing time-sharing problems were not experienced by the functionally specialised vertical operators and consequently the plotting performance of the first operator was not affected so severely. Tasks of this type do not appear to lend themselves to autonomy of operators at high levels of input complexity.

3.2

EXPERIMENT 2: The effect of input presentation rate on the performance of teams organised in vertical and horizontal structures, using a computer-assisted task

A previous experiment (Experiment 1: Chapter 3.1) used a task adapted from manual bearings-only analysis to compare the performance of teams organised in vertical and horizontal structures. When the presentation rate of inputs was increased, a vertical team organisation tended to be superior to the horizontal in terms of plotting errors on the time-bearing plot. Errors made by teams organised horizontally were mainly omissions, due to difficulties in time-sharing between the construction of the time-bearing and local operations plots. The high degree of motor demands inherent in the tasks, together with the low level of intra-task organisation between them, appeared to be the main causes of overload on the horizontal operators.

The present experiment is the first of a series to use tasks where operators have computer-assistance. Although the task content is similar to that of the task used in the first experiment, being essentially one involving identification, plotting, and reporting functions, there are various software aids available to the operators. These aids should affect various characteristics of the tasks to be performed, primarily the intra-task organisation between tasks through closer integration of the tasks to be performed, and by reducing the overall complexity of the tasks by removing many of the time-consuming motor demands, e.g. the manual construction of graphical plots is replaced by the pressing of the appropriate key for a plot to be made. It would be expected that the severe time-sharing problems encountered by the horizontal team arrangement in Experiment 1, should now be reduced considerably. The rate of presentation of contact information is again used to determine the level of input complexity.

METHOD

a) Task and Equipment

A computer-aided simulation of a naval task was used in which teams of two operators were required to identify, plot, and report on the movements of other vessels in the surrounding area. Range and bearing information is presented at regular time intervals on a hard copy printer (DEC writer). Fig. 3.2.3 shows the equipment layout with two operators seated at their graphics terminals. (Tektronix 4006 and Tektronix 4010). The printer can be seen between the two terminals.

Operators process bearing information with a question-and-answer routine - details of the latter can be found in the instructions/job aids for each experimental condition reproduced in Appendix I, and photographs appear in Figs. 3.2.4 - 3.2.8. Each experimental session is under program control throughout. Further details of the programs used in running the experiment and in the construction of the task can be found in Chapter 3.0.

Initially, teams are required to assign a track label to each piece of contact information. To assist them, operators can call for a tabular listing of recent label assignments to be produced on their screen. If a wrong label is assigned, the program will output an error message so that it may be corrected. This is to ensure that the second task, which depends on information output from the first, is not confounded by incorrect data. After being labelled, the contact information, still individually identified by a code number, must be plotted in order that track movements may be noted. As X-Y co-ordinates are calculated by the track program, the operator has only to express a desire to plot by pressing the appropriate key.

Thereafter, a graphic plan of all points plotted is available to the operator and it is then possible to detect any changes in the course of a particular track or any changes in speed. A sample of tracks used in the experiment is shown in Appendix III. Course or speed changes must be reported verbally and these are recorded. Indeed, both team members wear headsets with microphones so that they may converse freely throughout the experiment. The only exception to this is when a report must be made. Push-buttons are provided so that an operator wishing to report may cut off the inter-operator communication channel and speak without interruption. (See Fig. 3.2.3).

b) Subjects, Design, and Procedure

The subjects were 12 male and 12 female volunteers drawn from the student population of the University. None had previous experience of naval tasks, although 15 had served as subjects in the previous experiment (see Chapter 3.1: Experiment 1) using a task adapted from manual bearings-only analysis. However, the latter task and the present task are sufficiently different in nature for any advantage to be gained in terms of transfer. Females were randomly assigned to 6 teams of 2 operators: males to a further 6 teams of 2 operators. All subjects were paid for their services.

The independent variables used were the organisation of the team (along vertical or horizontal lines) and the input complexity (3 levels: low, medium, and high). In a split-plot factorial design with repeated measures (see Fig. 3.2.1) six teams composed of 3 male and 3 female experienced all levels of load under one type of organisation.

		Complexity		
		Low	Medium	High
Team Organisation	Vertical	$T_1 - T_6$	$T_1 - T_6$	$T_1 - T_6$
	Horizontal	$T_7 - T_{12}$	$T_7 - T_{12}$	$T_7 - T_{12}$

Fig. 3.2.1: Experimental Conditions (T denotes team)

(i) Complexity: there were three separate 15 minute experimental periods of different loadings, with a 2 minute rest interval between them. Four tracks were used, each one being constructed by the experimenter to have periods of low, medium and high complexity as defined by the number of contacts per unit time, e.g. see Appendix III and Fig. 3.2.2. The number of reportable changes was varied in relation to the input complexity.

To counteract any practice effects that may occur, or effects due to the onset of fatigue, the order ofconditions was balanced, i.e. 2 teams from each type of organisation experienced complexity in the order 'Low-Medium-High' (LMH). Similarly, the orders 'HML' and 'MHL' were used.

(ii) Organisation:

(a) Vertical: with a vertical team organisation, one operator was responsible for labelling all contact information on all four tracks, whilst his fellow team member was to plot contacts for all tracks and also report on any course or speed changes, i.e. a functional division of labour. As seen in Fig. 3.2.6 and the job aid (Appendix I) the first operator carries out a minimum of three actions culminating in his choosing a correct label. This information passes automatically to the printer (see Fig. 3.2.4) to be communicated to the second operator who carries out a minimum of three further operations to plot contacts, (see Fig. 3.2.7). He may then go on to report if required.

	Complexity		
	Low	Medium	High
Presentation rate	4 per 160 seconds	4 per 120 seconds	4 per 80 seconds
No. tracks	4	4	4
No. contacts	20	30	40
No. changes	8	16	24

Fig. 3.2.2: Task complexity

(b) Horizontal: the four targets were divided so that each team member was responsible for labelling, plotting and reporting on two of them. Tracks were constructed so that two of them moved across the bearing region 270^{o} - 090^{o} and the other two between 091^{o} - 269^{o}. The two former were the responsibility of one operator: the two latter the other operator. This prevented interference (or crossing) between the tracks of the two operators.

Contact information appeared on the printer as shown in Fig. 3.2.5. Each operator then selected those contacts occurring in his own area of responsibility and showed his acceptance by

Fig. 3.2.3: Workstation Arrangement

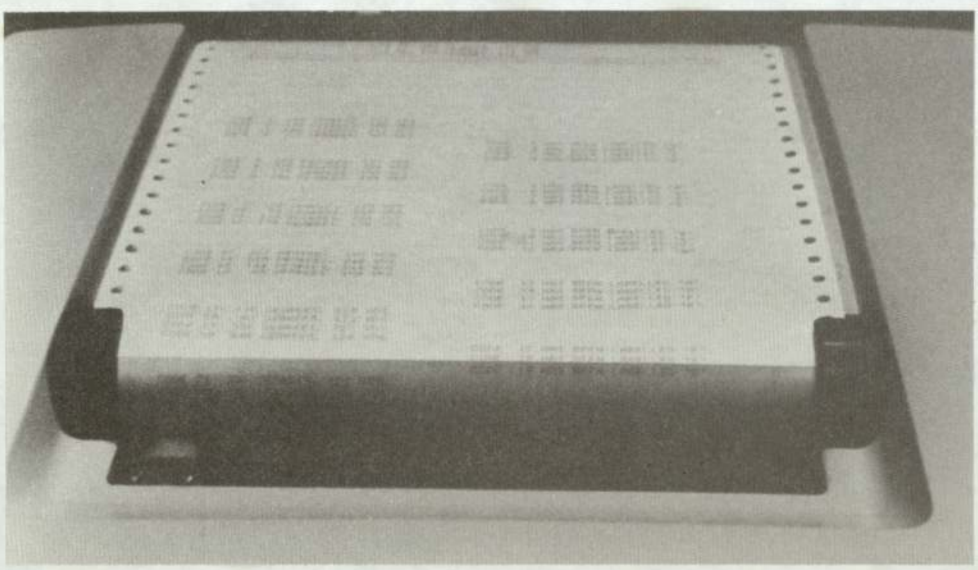
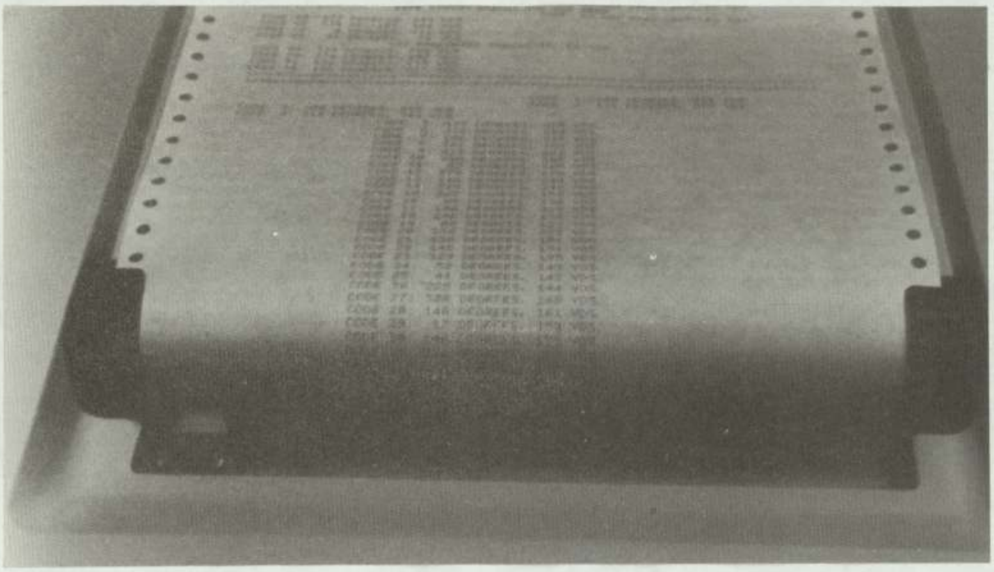
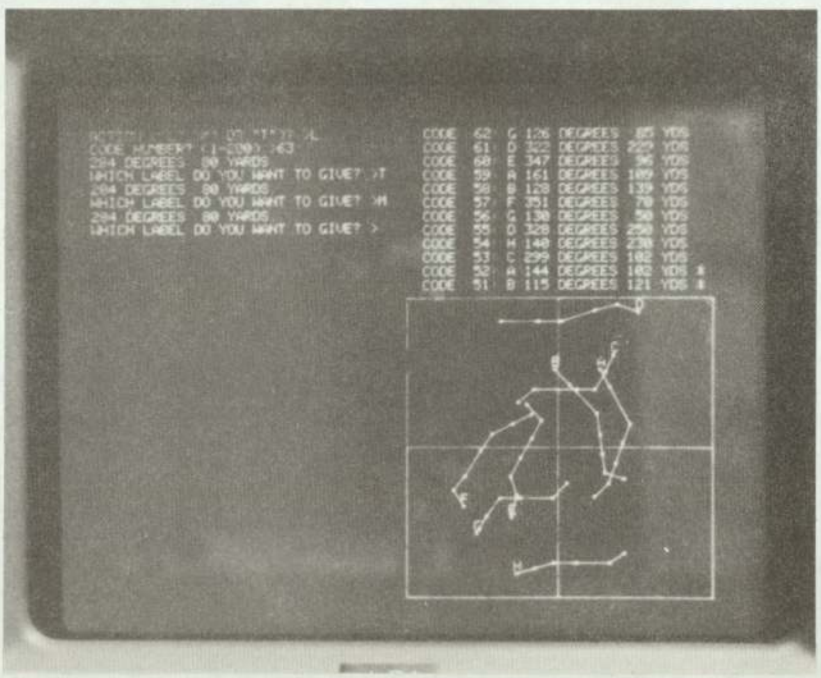


Fig. 3.2.4: Input to Vertical Operators



<u>Fig. 3.2.5: Input to Horizontal Operators</u>



<u>Fig. 3.2.6: Question-&-Answer Routine
Vertical Operator 1</u>

N.B. Photograph taken from later experiment. In Expt. 2, only four tracks used with tracks remaining in either top or bottom section, i.e. no 'crossovers'

Fig. 3.2.7: Question-&-Answer Routine
Vertical Operator 2

Fig. 3.2.8: Question-&-Answer Routine
Horizontal Operator 2

entering the appropriate contact number in his question-and-answer routine. Verbal or written communications between operators were not necessary. The job aid (Appendix I) shows that a minimum of four operations were required to plot a contact (see also Fig. 3.2.8).

There was a briefing period of 40 minutes before each experimental session during which the nature and the purpose of the task were explained to the subjects. In this period, a 15 minute practice took place when subjects actually performed their tasks whilst being 'talked through' by the experimenter. For both practice and experimental sessions, the relevant keys on the keyboard were labelled, so that no unfair time advantage would accrue to subjects already acquainted with the layout.

c) Performance Measures

(i) Time measures: a complete on-line timed transcript of the interaction between computer and operators was recorded on magnetic tape during each experimental run. From this, it was possible to calculate response times for certain significant events. The key measure was the time taken to plot since, before a contact was actually plotted, it was impossible to observe the movement of that particular vessel. The plot time was taken from when the contact first appeared on the printer to when the operator actually pressed the appropriate key to plot it. This time was further divided into: (i) waiting, or queuing time - the period elapsing between first appearance of the contact on the printer and the time its processing began - and: (ii) the time actually spent in processing the contact.

Plot time = Waiting time + Process time

The process time was further divided into: (i) the time taken to choose a label - the period elapsing between acceptance of the contact on to his terminal by the operator and his attaching the correct label and registering his response - and: (ii) the time taken to communicate this response and make a plot.

Process time = Time to choose label + Communication time

The sixth time measure taken related to the reporting task. For correct reports only (see 'Accuracy measures' below) the time period was measured between plotting a contact and reporting on any course or speed change on that track. The latter measure was made possible through an 'interrupt' being registered and recorded every time an operator pressed his button to report.

(ii) Accuracy measures: these related mainly to the reporting task where two measures were taken: the number of correct reports made, and the number of errors. The latter measure included the number of incorrect reports, the number of false alarms (reporting when there has been no change), and the number of misses (failing to report when a course or speed change had occurred). Two other measures were taken: the number of wrong labels given and the number of contacts plotted. The former measure, though related to time, can be thought of as an accuracy measure since failing to reach the stage of plotting a contact is equivalent to the construction of an incorrect track.

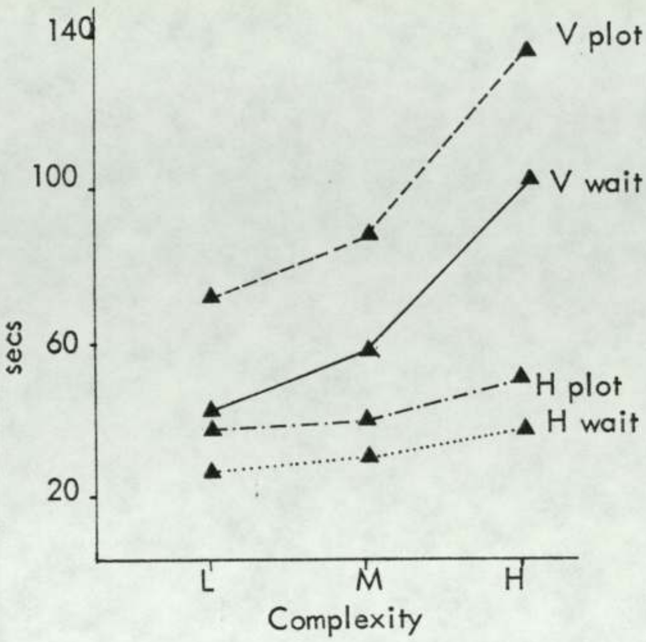
(iii) Other measures: all conversation between operators was recorded to determine the amount and content. In a de-briefing period following the experimental session, subjects were asked to describe their feelings about the task.

RESULTS

a) Time measures

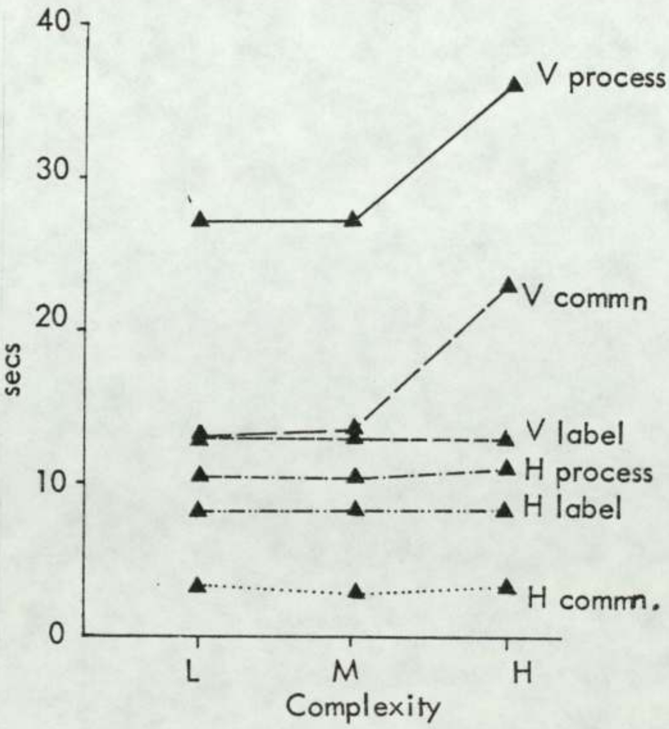
It can be seen from the graphed means in Fig. 3.2.9 that as comp was increased, there was an increase in the time taken to plot contacts. An analysis of variance carried out on this data (details of all analyses of variance carried out on experimental data can be found in Appendix VIII) shows the significant effect of the comp variable on this measure, $F\ (2,20) = 14.38$, $p<0.01$. There is also a significant difference between the performances of teams organised in vertical and horizontal modes, $F\ (1,10) = 85.45$, $p<0.01$. Further investigation of the significant comp x organisation interaction, $F\ (2,20) = 7.39$, $p<0.01$, by a simple main effects analysis shows that the significant organisation difference is found at all levels of comp: low, $F\ (1,30) = 14.36$, $p<0.01$; medium, $F\ (1,30) = 27.99$, $p<0.01$, and high, $F\ (1,30) = 103.19$, $p<0.01$. The increasing values of F with increasing comp appear to denote a relative decline in performance of vertical against horizontal performance as comp increases.

When the plot time is sub-divided into its constituent wait and process elements, it is found that the above horizontal superiority on overall plot time is reflected to a great extent in differences between the performances of vertical and horizontal structures on both measures, $F\ (1,10) = 22.37$, $p<0.01$ and $F\ (1,10) = 433.19$, $p<0.01$ respectively. A simple main effects analysis carried out on waiting time shows that whilst no significant differences between organisation exist at low comp the vertical performance on this measure does decline relative to horizontal at both medium, $F\ (1,30) = 13.06$, $p<0.01$, and high comp levels, $F\ (1,30) = 48.74$, $p<0.01$. However, whilst a significant complexity



<u>Fig. 3.2.9</u>:

<u>Av. plot time</u>
<u>(with Av. wait time)</u>



<u>Fig. 3.2.10</u>:

<u>Av. process time</u>
<u>(with Av. label time</u>
<u>and Av. communication</u>
<u>time)</u>

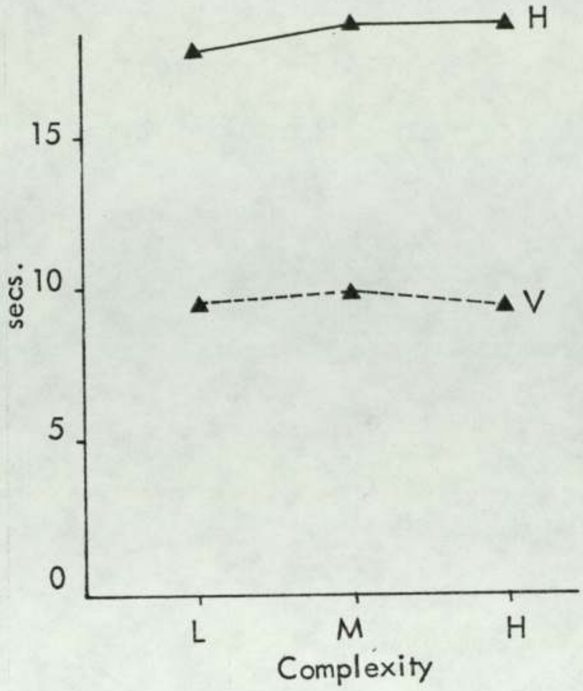


Fig. 3.2.11:

Av. plot-report time

effect is found on overall wait time, F (2,20) = 10.37, p<0.01, such an effect is not found on overall process time.

A further breakdown of process time into its constituent label time and communication time elements again shows significant differences between organisations on both measures, with horizontal superiority on labelling, F (1,10) = 26.21, p<0.01, and horizontal superiority on communication time, F (1,10) = 81.60, p<0.01. Although not affecting labelling time significantly, the comp variable does affect the time taken to communicate, F (2,20) = 4.47, p<0.05, and further analysis of the interaction effect, F (2,20) = 4.62, p<0.05, shows increasingly superior horizontal performance at all comp levels: low, F (1,30) = 27.15, p<0.01; medium, F (1,30) = 28.87, p<0.01 and; high, F (1,30) = 97.06, p<0.01, (see also Fig. 3.2.10).

On the sixth time measure the time elapsing between plotting and reporting, the vertical method of organisation is superior, $F(1,10) = 9.97$, $p<0.05$.

b) Accuracy measures

Both comp and organisation have a significant effect on the number of plots completed, $F(2,20) = 20.39$, $p<0.01$, and $F(1,10) = 65.94$, $p<0.01$ respectively. The horizontal organisation is more effective than the vertical and the significant interaction effect, $F(2,20) = 14.34$, $p<0.01$, further emphasizes the difference with performance under vertical organisation falling disproportionately as comp increases. Indeed, a simple main effects analysis of this data shows a larger organisation difference at high complexity $F(1,30) = 80.53$, $p<0.01$, than at medium comp, $F(1,30) = 5.94$, $p<0.05$, with no significant difference at the low comp level.

The vertical organisation is inferior to horizontal in terms of the number of wrong labels chosen (see Fig. 3.2.13) although this difference is not statistically significant. More wrong labels are chosen under both types of organisation as complexity increases. The same is true for the percentage of correct reports made, (see Fig. 3.2.14), although here the level of comp has a significant effect, and the performance of the vertical organisation does appear to deteriorate more so at the high comp level. The decrement is reflected to some extent in the number of reporting errors made by teams, which increase significantly, $F(2,20) = 31.13$, $p<0.01$, as comp increases.

Although there are no significant differences in total errors made under the two organisations, these errors can be subdivided into those due to omissions and those due to inaccurate reporting and false alarms. Errors of omission increase

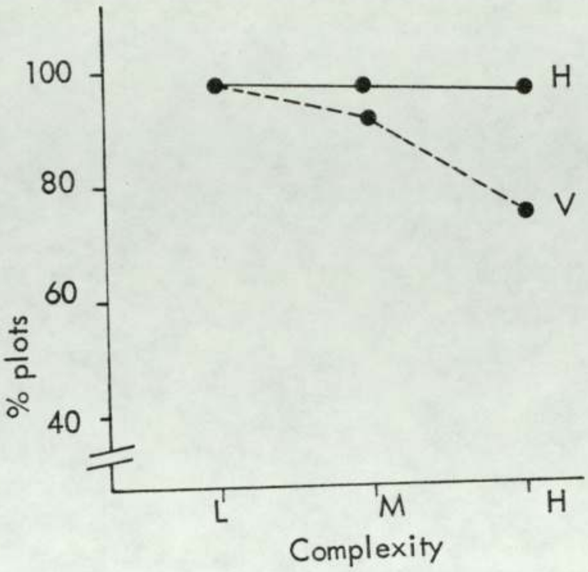


Fig. 3.2.12:

Av. no. completed plots (%)

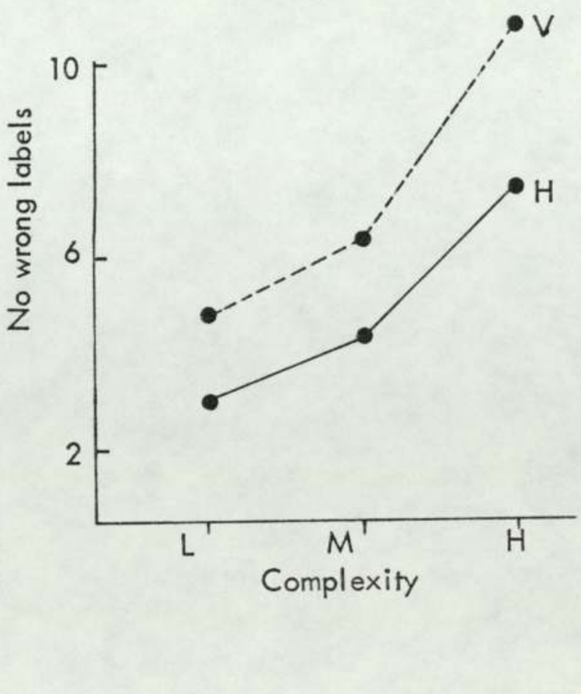


Fig. 3.2.13:

Av. no. wrong labels

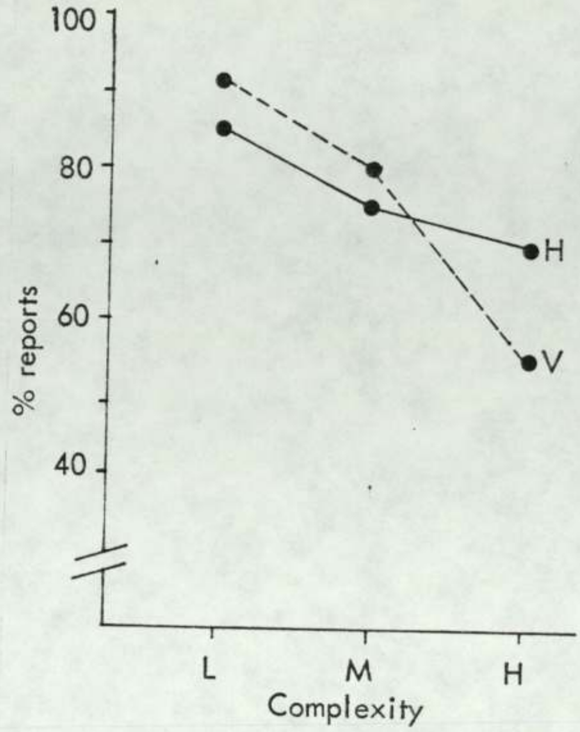
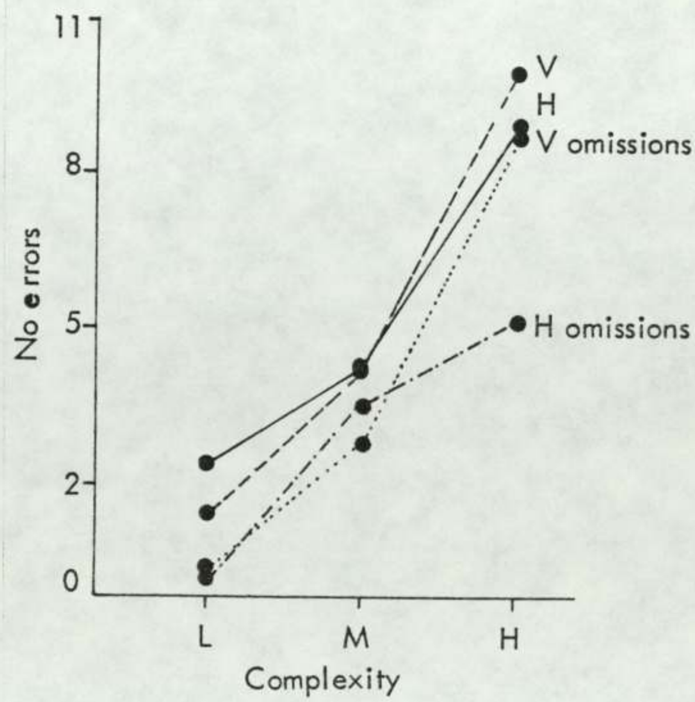


Fig. 3.2.14:

Av. no correct reports (%)

Fig. 3.2.15:

Av. no. report errors (showing errors of omission)



significantly with increases in comp, $F(2,30) = 37.05$, $p<0.01$, and further analysis of the interaction effect, $F(2,30) = 8.22$, $p<0.01$, demonstrates a disproportionate decline in vertical performance on this measure at the high comp level, $F(1,30) = 18.44$, $p<0.01$. False alarms and inaccurate reports do not differ significantly between organisations (or with comp) but are generally higher under the horizontal organisation (see Fig. 3.2.15) as comp increases.

c) Other measures

Since communication in this task is essentially of a written nature, the tape recordings of verbal communication yielded nothing of value except for the reporting comments. Operators working in the horizontal mode tended to work as individuals rather than as a team and only spoke when deciding on their appropriate contact information at the beginning of the task. Otherwise, there was little meaningful task-relevant communication.

In their post-task verbal reporting, operators under both types of organisation complained of boredom in the low complexity conditions. Those who had been organised in horizontal fashion generally enjoyed the high comp conditions, but this was not so for the vertical mode, where the first operator (labelling) was generally overloaded for most of the time.

DISCUSSION

The superiority of the horizontal organisation in terms of lower response times is perhaps the most noticeable aspect of the results. Although both forms of team organisation had higher overall plot times with increasing input presentation rate, the vertical organisation was generally inferior on plot time and its constituent waiting and process time elements. Vertical waiting time increased disproportionately to horizontal waiting time as comp increased, especially so in the high comp condition when the first operator could not keep up with the increased rate of presentation of contacts. This resulted in more 'queuing' of contacts on the printer prior to their being processed, and to higher waiting times. Superiority of the horizontal organisation is again evident in the time taken to process contacts after their acceptance. Both label times and communication times are significantly higher for the vertical organisation. The former is most probably due to the first vertical operator having to choose each time from twice the number of alternatives as the operators working in the horizontal structure, but the latter is clearly due to the extra operations involved in the vertical organisation. These are necessary in this task for vertical operators to communicate with each other, whilst the autonomy of horizontal operating does not require them. Once a plot was made, the time taken to report (if required) was significantly lower for the vertical organisation. Much of this difference was due to the second vertical operator being specifically responsible for reporting whereas, to aid their time-sharing, horizontal operators would often plot several contacts before reporting where required.

The wider choice also made for the choosing of more wrong labels by vertical operators but elsewhere there were no significant differences in accuracy between the two forms of organisation. The percentage of correct reports fell, and report errors increased, as comp increased. Omissions accounted for 88.3% of vertical report error at the high comp level - longer response times meant that fewer plots were made and consequently fewer reports were possible. The corresponding figure for the horizontal organisation was 49.5% - it would appear that whilst plots were more often completed, the time pressures contributed to a large proportion of inaccurate reporting and false alarms.

Differences in activity were evident. Under high comp, when the first vertical operator was most stressed, the resultant queuing of contact information led to under-activity of the second operator. Perhaps performance may have been improved had vertical operators been encouraged to help each other, when possible. Horizontal operators, on the other hand, appeared to, and felt that they were, working optimally in the medium and high comp conditions. All teams complained of boredom in the low complexity conditions and this might account for the reporting errors.

In conclusion, then, the superior horizontal response times made for a better rate of plotting than the vertical organisation. The horizontal structure performed better than vertical on all constituent elements of the plot time - waiting time, label time, and communication time. The former rose with comp, as the first vertical operator could not keep up with contact presentation whilst the latter is an inevitable consequence of the organisation of the task. As a consequence of these higher response times, the vertical organisation plots fewer contacts. This inevitably leads to more errors particularly those due to omissions. Horizontal operators appear to have benefitted from the high level of intra-task organisation between the identification, plotting, and reporting tasks. The vertical organisation, however, could not take full advantage of such task integration because of the inter-task organisation between first (identification) and second (plot and report) operators. This need for co-operation between vertical operators added to the complexity of the overall team task and was a major contributor to overall response times.

3.3

EXPERIMENT 3: The effect of number of alternative choices on the performance of teams organised in vertical and horizontal structures, using a computer-assisted task.

When the presentation rate on four tracks was increased, it was found that a vertical organisation was inferior to a horizontal organisation in terms of response times and the amount of correct reports and reporting error (see Chapter 3.2: Experiment 2). The vertical organisation became overloaded especially at the higher presentation rate and performance consequently fell relative to the horizontal organisation.

The following experiment, using the same computer-assisted task as before, investigates the effect of varying input complexity by increasing the number of tracks, keeping presentation rate constant. This should impose a greater discriminatory load on operators. The other independent variable is again the organisation of the team and of main interest will be how the time-sharing horizontal operators will cope with the increased number of choices in relation to the first vertical operator. The latter will also have more tracks to choose from, but his functional specialisation may be advantageous.

METHOD

a) Task and Equipment

The task used in this experiment - a computer-aided simulation of a naval picture compilation task - was essentially the same as that utilised in the last study. From range and bearing information, teams of two operators, seated at graphics terminals, identify, track, and report on the movements of other vessels in the surrounding area. A question-and-answer routine (see Appendix I) is followed, each experimental session being under program control throughout. Indeed, the job aid for this experiment is identical to that for the last experiment, except that subjects are instructed to use up to 8, as opposed to 4, track labels.

Each piece of contact information must first be given a track label, before being plotted, so that track movements may be noted. Operators may then consult a graphic plan of all points plotted, from which they can detect any changes in the course of a particular track, or any changes in speed. A sample of tracks used in this experiment is shown in Appendix IV. Such course or speed changes must be reported verbally via the headsets worn by operators. Tracks were constructed so that 4 of them moved only in the region 270^{o} - 090^{o}, and 4 only in the region 091^{o} - 269^{o}.

b) Subjects, Design and Procedure

The subjects were 24 undergraduate volunteers drawn from the student population of the University, all of whom had no previous experience of naval tasks. They were randomly assigned to 12 teams of two operators. All were paid for their services.

The organisation of the team and the complexity were again the independent variables.

(i) Organisation: with a vertical organisation, one operator was responsible for labelling all contact information for all tracks, with the second operator plotting and reporting on contacts for all tracks. (See the job aid: Appendix I). In the horizontal method of team organisation, each operator labelled, plotted and reported on information relating to their own tracks. One operator was responsible for the bearing region 270° - 090°: the other 091° - 269°.

(ii) Complexity: three complexity levels were used, depending on the number of tracks, which varied through 4 (low comp), 6 (medium comp) and 8 (high comp). Each level was presented during experimental periods of 20 minutes with a 2-minute rest interval between them. A presentation rate of 4 contacts per 120 seconds (equivalent to the medium comp presentation rate of the second experiment: Chapter 3.2) was used throughout.

	Complexity		
	Low	Medium	High
Presentation rate	4 per 120 seconds	4 per 120 seconds	4 per 120 seconds
No. tracks	4	6	8
No. contacts	40	40	40
No. changes	12	18	24

Fig. 3.3.1: Task Complexity

Although the number of contacts remained constant, the number of reportable changes was varied in relation to the number of tracks (Fig. 3.3.1).

In a split-plot factorial design with repeated measures six teams experienced all levels of comp under one type of team organisation (see Fig. 3.3.2).

The order of conditions was balanced to counteract practice or fatigue effects, so that three teams from each type of organisation experienced complexity in the order 'Low-Medium-High'

		Complexity		
		Low	Medium	High
Team Organisation	Vertical	$T_1 - T_6$	$T_1 - T_6$	$T_1 - T_6$
	Horizontal	$T_7 - T_{12}$	$T_7 - T_{12}$	$T_7 - T_{12}$

Fig. 3.3.2: Experimental Conditions (T denotes team)

(LMH): the other three HML.

A 40 minute briefing period preceded each experimental session during which subjects were 'talked through' a 15 minute practice period by the experimenter. Relevant keys were labelled on the keyboard.

(c) Performance Measures

These were the same as those taken in the second experiment, (Chapter 3.2), where their derivation is described in detail. Time measures were once again: (i) the time taken to plot; (ii) waiting time; (iii) processing time; (iv) labelling time; (v) communication time; and (vi) the time elapsing between plot and report for correct reports only. Accuracy measures were again: (i) the number of contacts plotted; (ii) wrong labels; (iii) correct reports and; (iv) reporting error (misses, inaccurate reporting, and false alarms).

All conversation between operators was again recorded and they were asked to describe their feelings about the task in a de-briefing period.

RESULTS

a) Time measures

Under both types of organisation, the time taken to plot increased significantly with increases in comp, $F(2,20) = 18.03$, $p<0.01$ (see Appendix IX for all analyses of variance carried out on experimental data) with the horizontal organisation being superior to the vertical organisation, $F(1,10) = 16.99$, $p<0.01$. A simple main effects analysis carried out on the interaction effect, $F(2,20) = 13.71$, $p<0.01$, demonstrates the general superiority at all levels of comp of the horizontal organisation: low, $F(1,30) = 20.82$, $p<0.01$; medium, $F(1,30) = 6.81$, $p<0.05$; and high, $F(1,30) = 79.58$, $p<0.01$. The plotted means in Fig. 3.3.3 further show these differences.

The horizontal organisation is also superior on both waiting time, $F(1,10) = 7.79$, $p<0.05$, and the time taken to process contacts, $F(1,10) = 18.72$, $p<0.01$. Comp, too, has a significant effect on waiting time, $F(2,20) = 18.44$, $p<0.01$ and this, too, is evident from Fig. 3.3.3. A simple main effects analysis on the significant interaction effect, $F(2,20) = 8.07$, $p<0.01$ shows no significant differences between organisation except at the high comp level, $F(1,30) = 44.59$, $p<0.01$. Although process time generally increases with comp (see Fig. 3.3.4) the effect is not significant.

The time to label also increases with comp (see Fig. 3.3.4) but the effect is not significant. There is also significant difference between performances on this measure of different organisations although the horizontal organisation is superior to the vertical, $F(1,10) = 19.17$, $p<0.01$ in time taken to communicate, but the comp has little effect on this measure.

The vertical organisation is superior on the time elapsing between the plotting and reporting: $F(1,10) = 19.58$, $p<0.01$.

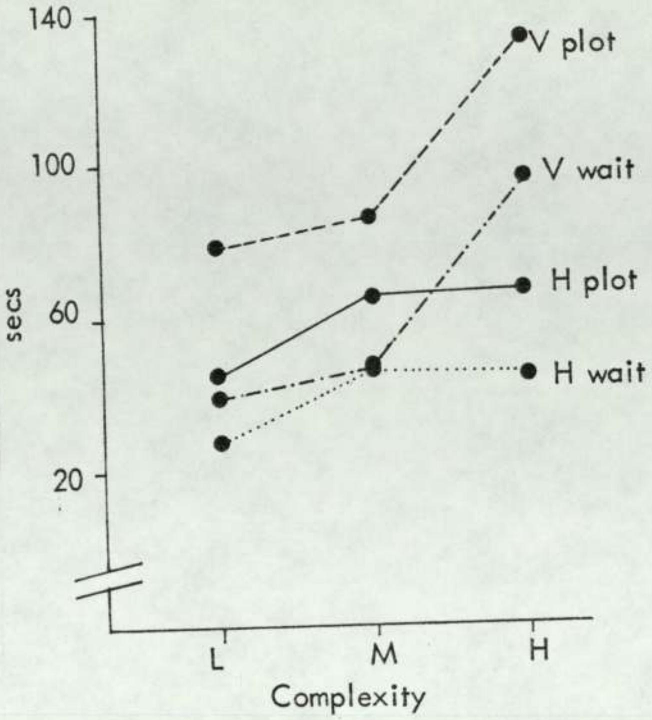
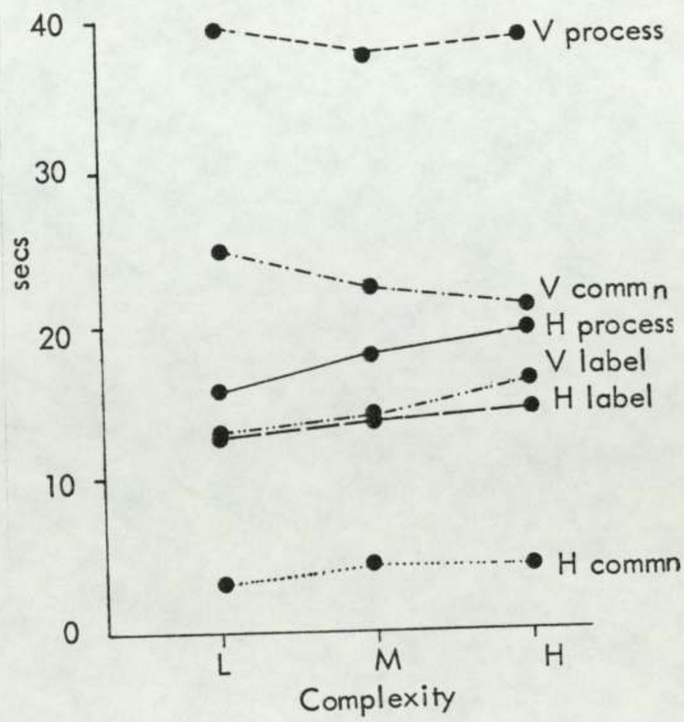


Fig. 3.3.3:

Av. plot time (with Av. wait time)

Fig. 3.3.4:

Av. process time (with Av. label time and Av. communication time)



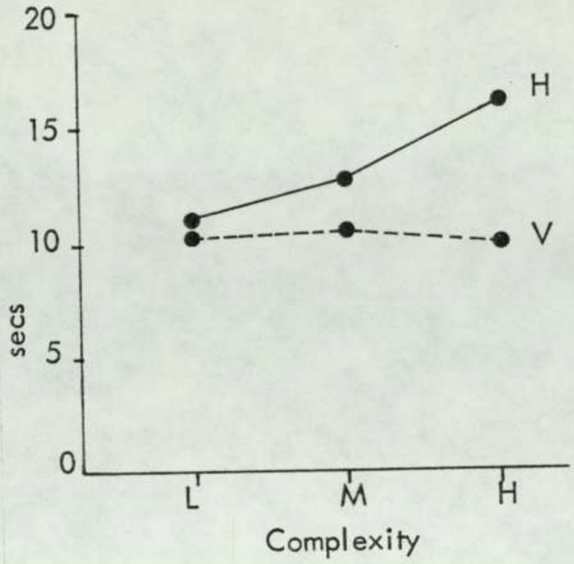


Fig. 3.3.5:

Av. plot-report time

Comp also affects this measure, F (2,20) = 4.64, p<0.05, and simple main effects analysis of the comp x organisation interaction, F (2,20) = 5.18, p<0.05, reveals increasing superiority at higher comp levels: medium, F (1,30) = 11.32, p<0.01, and high, F (1,30) = 50.29, p<0.01. This is further evident from Fig. 3.3.5.

b) Accuracy measures

Comp has a significant effect on the number of plots completed, F (2,20) = 10.43, p<0.01, but there is no significant difference between different organisations on this measure. However, further examination of the interaction effect, F (2,20) = 3.79, p<0.05, reveals a disproportionate decline at high complexity level only, F (1,30) = 24.06, p<0.01, by the vertical organisation (also see Fig. 3.3.6).

Neither comp nor organisation affects the number of wrong labels chosen although, from Fig. 3.3.7, it can be seen that

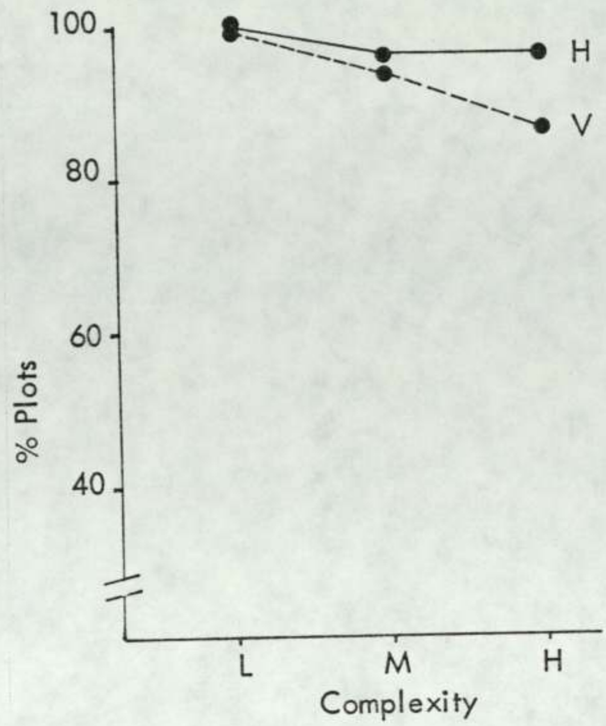
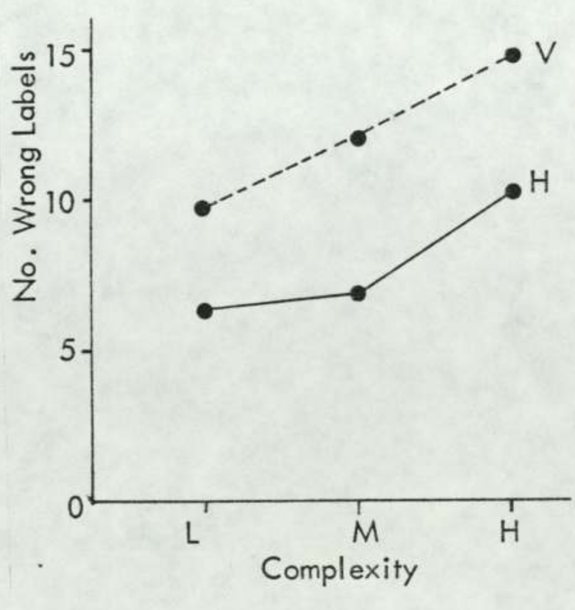


Fig. 3.3.6:

Av. no. completed plots (%)

Fig. 3.3.7:

Av. no wrong labels



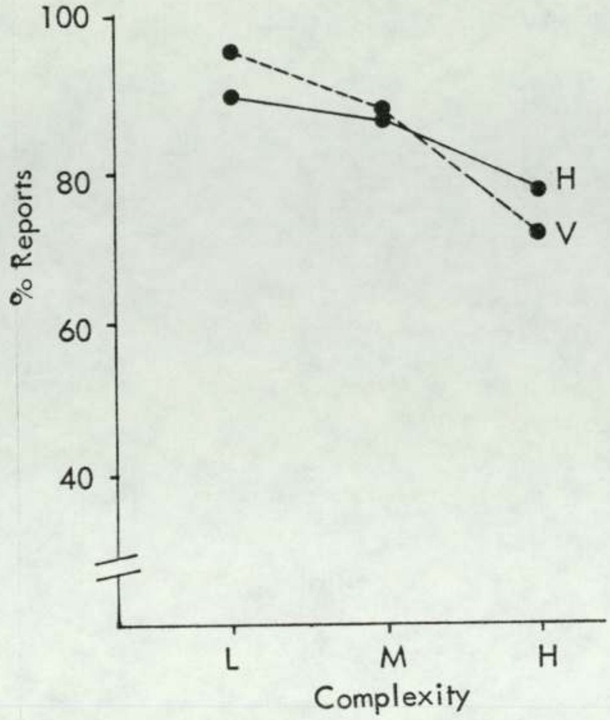
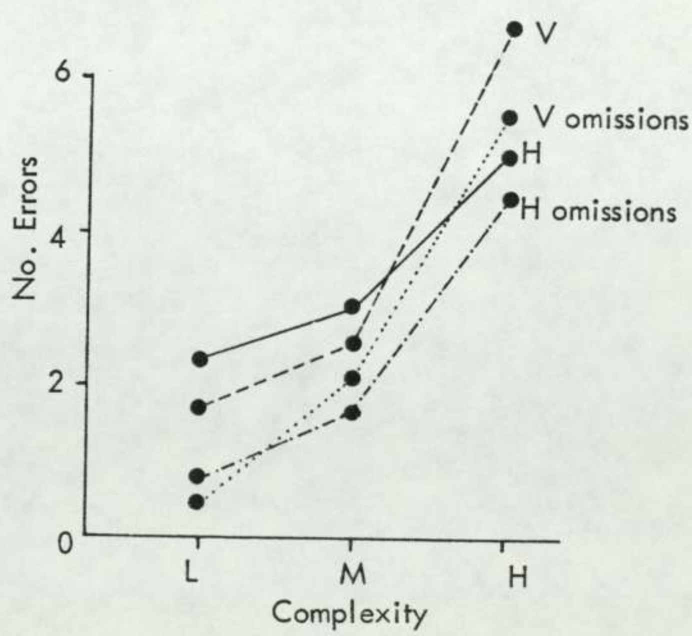


Fig. 3.3.8:

Av. no. correct reports (%)

Fig. 3.3.9:

Av. no. report errors (showing errors of omission)



these do increase with comp, and the horizontal organisation is always superior.

Only comp affects the number of correct reports made, $F\ (2,20) = 11.84$, $p<0.01$, and the number of reporting errors, $F\ (2,20) = 12$, $p<0.01$. There are no significant differences on these measures between the two modes of organisation, but it can be seen from Figs. 3.3.8 and 3.3.9 that vertical appears to decline more so at high comp levels.

There are no significant differences between organisations in either measure of error type: inaccurate reports and false alarms or omissions. However, the level of the latter is significantly affected by the comp, $F\ (2,20) = 15.21$, $p<0.01$. Fig. 3.3.9 demonstrates the amount of errors of omission against total report error.

c) Other measures

There was little meaningful task-relevant communication, since communication in this task is essentially of a written nature. Also, those operators organised in a horizontal fashion again appeared to enjoy the task more so than those in the vertical mode, where the first operator was overloaded in the high comp condition.

DISCUSSION

The response times for the horizontal organisation are generally superior to those of the vertical organisation. Plot time is significantly different, as are its constituent elements of waiting time and process time. The difference on waiting time is not so marked, however, except at the high comp level. This is because of the constant presentation rate - only at the high comp level when the first vertical operator must discriminate between 8 tracks does 'queuing' of contacts and, hence waiting time rise disproportionately. The difference in process time is chiefly due to the communication time, again due to the extra operations involved in the vertical organisation. The other element of process time, the time taken to choose a label, rises with comp, but there is little difference between different team organisations. That there is not therefore an equivalent rise in horizontal waiting time at the high comp level is probably because of the nature of presentation of contact input data on the printer. Although contacts from different tracks are randomised, the horizontal operators often 'share' the four contacts presented at one time and so do not incur high levels of waiting time. Plot-report times are higher for the horizontal organisation at all comp levels. As was the case in Experiment 2 (Chapter 3.2), this was mainly due to the specialisation of the second vertical operator, and the plotting of several contacts by horizontal operators prior to reporting where required.

Both types of team organisation plot a large proportion of contacts, although vertical falls disproportionately at the high comp level. There is a hint of plotting at the expense of reporting with the horizontal organisation at the high comp level. Omissions account for 88.2% of horizontal error and 83.8% of vertical error at this level. Consequently the percentage of correct reports falls at the high comp level, even though the horizontal organisation plots 96.6% of all contacts. The number of wrong labels chosen increase with comp with the vertical organisation choosing more than the horizontal, mainly because the first operator chooses from twice the number of alternatives as the horizontal operators.

The horizontal organisation is undoubtedly once again superior to the vertical organisation with shorter response times, more contacts plotted, more correct reports and less report error and incorrect labelling. However, the vertical organisation does perform better relative to the horizontal in this experiment - compared to Experiment 2 - when the presentation rate is kept constant - equivalent to the medium comp presentation rate of Experiment 2. There is less difference between organisations on waiting time and the increase in number of alternative choices also makes for relatively higher horizontal labelling and overall plot times. The increase in horizontal response times is reflected in the high proportion of errors due to omissions, whereas both types of organisation choose more wrong labels with an increase in the number of tracks. The communication time is again weighted against the vertical organisation but, in spite of this, the superiority of the horizontal organisation is again evident on a number of independent measures. Again, as in Experiment 2 (see Chapter 3.2) the high level of input complexity has produced an overload on the first vertical operator. Although the horizontal response times, too, increase, as discriminatory demands increase with the number of alternative choices to be made, this organisation again appears to benefit from the high level of intra-task organisation. The inter-task organisation in the vertical task again adds to the overall task complexity, whilst little inter-task organisation is necessary in the horizontal organisation where the two operators are able to act independently.

3.4

EXPERIMENT 4: The effect of increased co-ordination requirements on teams organised in vertical and horizontal structures, with reference to communication and display factors

Two previous experiments (Experiment 2: Chapter 3.2, and Experiment 3: Chapter 3.3) have compared teams organised in vertical and horizontal structures, working on an analogue of a naval picture compilation system. Comp was varied in two ways: in the first of the two experiments, the rate of presentation of contacts was varied whilst, in the second, the number of alternative tracks from which operators were required to choose was varied. In both experiments, the horizontal team organisation performed better than the vertical in terms of lower response times, more correct reports, and less labelling and report error at high comp levels. The vertical organisation performed relatively better against the horizontal when presentation rates were lower. Even though process time was higher for both organisations on Experiment 3, the lower presentation rate made for lower waiting times for the vertical organisation. Vertical plot times were therefore similar to Experiment 2, at all comp levels, but horizontal plot times were somewhat higher.

In order to increase the complexity of the task, the following experiment introduces 'crossovers' - tracks crossing between the different sectors of the two horizontal operators. Even though this should make little difference to vertical operators in labelling terms, since they will continue to label all contacts, the task should call for more co-ordination between horizontal operators - an increase in their inter-task organisation.

Also of interest in this experiment are communication and display factors. The horizontal organisation has been varied in three ways: (i) where operators have a whole display (in this case, the map or plot) giving all the information required for decision-making; (ii) operators have only their own plotting displayed - this gives less 'clutter' on the plot but calls for increased co-ordination between operators, and; (iii) as in (i) but with no communication allowed between operators. The latter form of organisation will be used to assess the beneficial or interfering effects of verbal communication.

In order to investigate the effects of practice on this task, the vertical organisation will be repeated in a further study (Experiment 4 (a)) against the horizontal organisation with the best performance on this experiment.

METHOD

a) Task and Apparatus

The experimental task again utilized the computer-aided simulation used in Experiments 2 and 3, and described in detail in Chapter 3.2. Teams of two operators were required to identify, track, and report on the movements of vessels in the surrounding area. Range and bearing information was again presented to operators who processed this by following a question-and-answer routine (see Appendix I). Each experimental session was under program control throughout.

Identification and plotting procedures were identical to those in Experiments 2 and 3 but, as well as reporting on course and speed changes, operators were also required to report any 'crossovers', i.e. when a track crossed between the sectors of the two horizontal operators. Tracks were constructed so that the number of crossovers varied with general task complexity (see Appendix V and Fig. 3.4.2 below). It was also necessary to ensure that operators in the horizontal structure had equal demands imposed on them.

b) <u>Subjects, Design and Procedure</u>

The subjects were 32 volunteers, paid for their services, drawn from the student population of the University, all of whom had no previous experience of naval tasks. They were randomly assigned to 16 teams of two operators.

The organisation of the team and the complexitywere again the independent variables:

(i) <u>Organisation</u>: a vertical team organisation was compared to a horizontal organisation, but the latter was varied in three ways, depending on the communication structure and the type of information display available:

a) Vertical:- one operator was responsible for labelling all contact information for all tracks, with the second operator plotting and reporting on contacts for all tracks. (see Appendix I).

b) Horizontal independent (H. ind.):- each operator labelled, plotted and reported on information relating to their own tracks. One operator was responsible for all contacts appearing between 270° - 090°: the other 091° - 269°. Both operators had a map at their disposal showing all their own plotted contacts as well as those made by the other operator. No communication was allowed on this condition. Indeed, communication was not necessary since

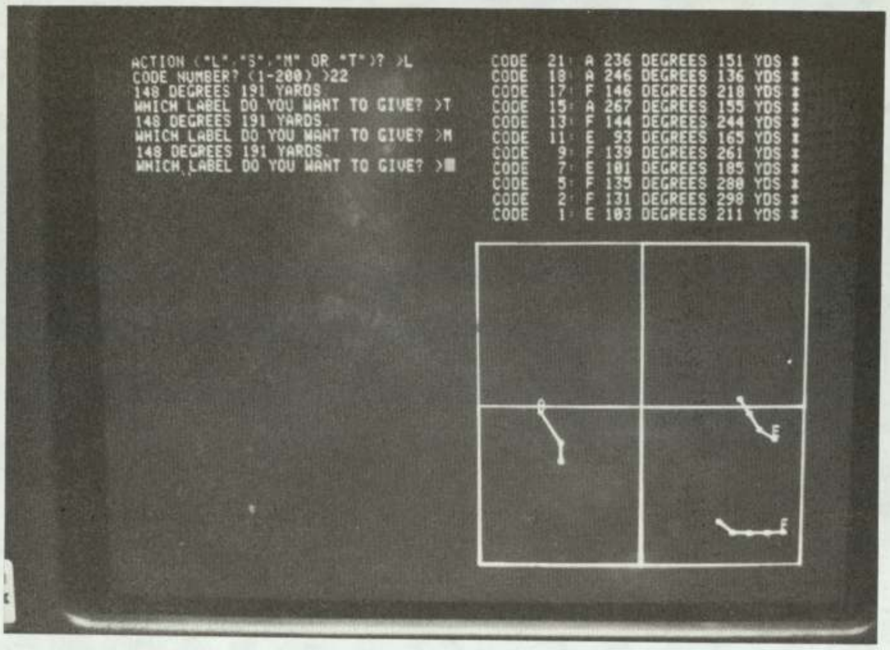


Fig. 3.4.1: The Partial Display

	Complexity		
	Low	Medium	High
Presentation rate	4 per 90 seconds	4 per 90 seconds	4 per 90 seconds
No. tracks	4	6	8
No. crossovers	2	4	6
No. contacts	40	40	40
No. changes	20	20	20

Fig. 3.4.2: Task Complexity

all the information required for decision-making was already available.

c) Horizontal co-operative (H. co-op):- as in b) above, but operators were allowed to communicate with each other.

d) Horizontal co-operative with partial display (H. part):- as in c) above, but operators had maps showing only their own plotted contacts for use in labelling, reporting and so on. Fig. 3.4.1 demonstrates the partial display with an example taken from the screen of the second horizontal operator. Also demonstrating the question-and-answer routine and table facility described fully in Chapter 3.2., the photograph shows the recent arrival of new track A into the operator's sector of responsibility. Track E, previously in this area has crossed over to the sector of the first operator, and is no longer the responsibility of the second operator. Communication was necessary here, where operators had to discuss track movements with each other, in order to aid the processing of contact information.

(ii) Complexity: three levels of comp were used, depending on the number of tracks and the number of tracks crossing between sectors. The number of contacts was the same for each comp level, as was the number of reportable changes. Each level was presented during experimental periods of 20 minutes with intervening rest intervals of 2 minutes. A presentation rate of 4 contacts per 90 seconds (Experiment 3: 4 contacts per 120 seconds) was used throughout.

In a split-plot factorial design with repeated measures, four teams experienced all levels of comp under one type of team organisation (see Fig. 3.4.3).

The order of conditions was balanced to counteract practice and fatigue effects. Two teams from each type of organisation experienced conditions in the order 'Low-Medium-High', with the two other teams 'High-Medium-Low'. All teams completed a practice session when they were 'talked through' by the experimenter.

		Complexity		
		Low	Medium	High
Team Organisation	Vertical	$T_1 - T_4$	$T_1 - T_4$	$T_1 - T_4$
	H. ind	$T_5 - T_8$	$T_5 - T_8$	$T_5 - T_8$
	H. co-op	$T_9 - T_{12}$	$T_9 - T_{12}$	$T_9 - T_{12}$
	H. part	$T_{13} - T_{16}$	$T_{13} - T_{16}$	$T_{13} - T_{16}$

Fig. 3.4.3: Experimental Conditions (T denotes team)

c) Performance Measures

These were the same as those taken in Experiments 2 and 3. Time measures were again: plot time, waiting time, and the time elapsing between plot and report. Accuracy measures were: number of contacts plotted, number of wrong labels, correct reports, and reporting errors. Their derivation is described in detail in Experiment 2. In addition, verbal communication measures were made in terms of: (i) the number of direct questions (requests for information, opinions, or evaluations); (ii) the number of direct responses (the provision of requested information, and the giving of opinions or evaluations); (iii) the number of volunteered messages (course of action, information, opinions, or evaluations) and; (iv) the number of irrelevant, or non-task-relevant communication. Verbal communication measures were taken from the last 10 minutes of recorded speech from each comp level.

RESULTS

a) <u>Time Measures</u>

On the overall plot time, no significant differences were found between the four types of team organisation. Only comp was significant, $F\ (2,24) = 14.99$, $p < 0.01$. (Analyses of variance and other statistical analyses on experimental data are all contained in Appendix X). However, it can be seen from Fig. 3.4.4 that the vertical organisation has consistently higher response times than the three horizontal organisations. This is reflected to some extent in the waiting time (see Fig. 3.4.5) but here again, only comp had a significant effect, $F\ (2,24) = 9.89$, $p < 0.01$. Except at the high comp level, the H. co-op response time is generally the highest.

With the other constituent of plot time - the time taken to process contacts (label plus communication time) - there is a significant organisation effect, $F\ (3,12) = 43.96$, $p < 0.01$. Further examination of this difference by a Tukey Multiple Comparison of Means analysis (see Appendix X) shows that this is mainly due to the inferior performance of the vertical organisation against the three horizontal organisations. Whereas no significant differences exist between all forms of horizontal organisation, the performance of the vertical organisation differs significantly (< 0.01) from them all. Similarly, the organisation effect on communication time, $F\ (3,12) = 59.99$, $p < 0.01$, is again due to inferior vertical performance. A Tukey Multiple Comparison of Means again shows the significant difference (< 0.01) between the vertical and the three horizontal organisations.

Label time increases significantly with comp, $F\ (2,24) = 28.29$, $p < 0.01$ but there is no organisation effect. Fig. 3.4.7 shows that

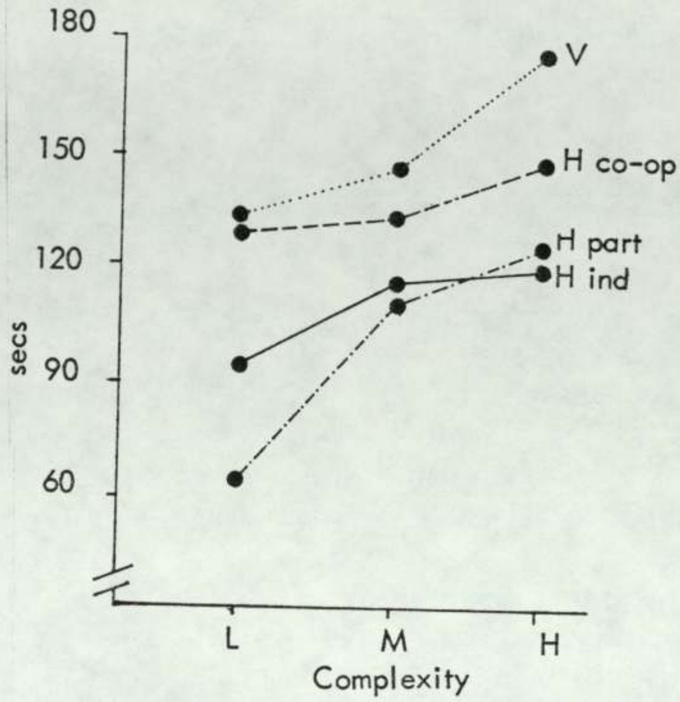
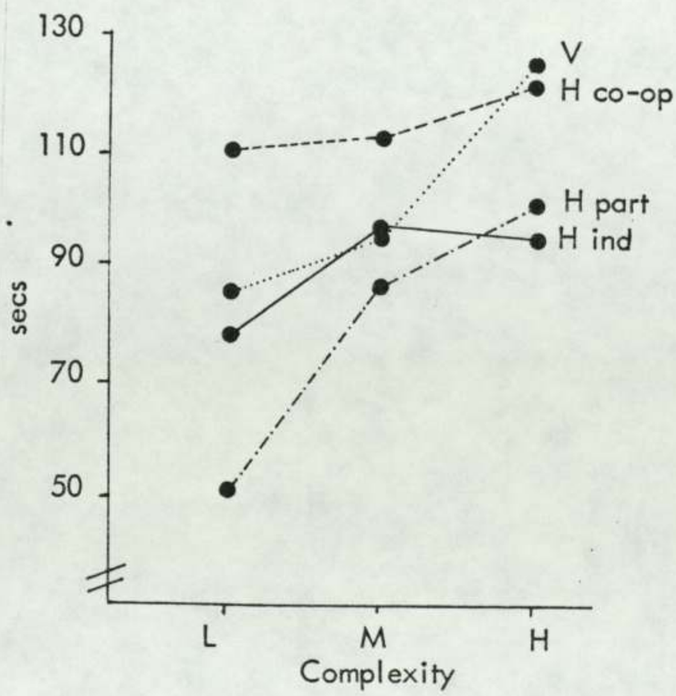


Fig. 3.4.4:

Av. plot time

Fig. 3.4.5:

Av. waiting time



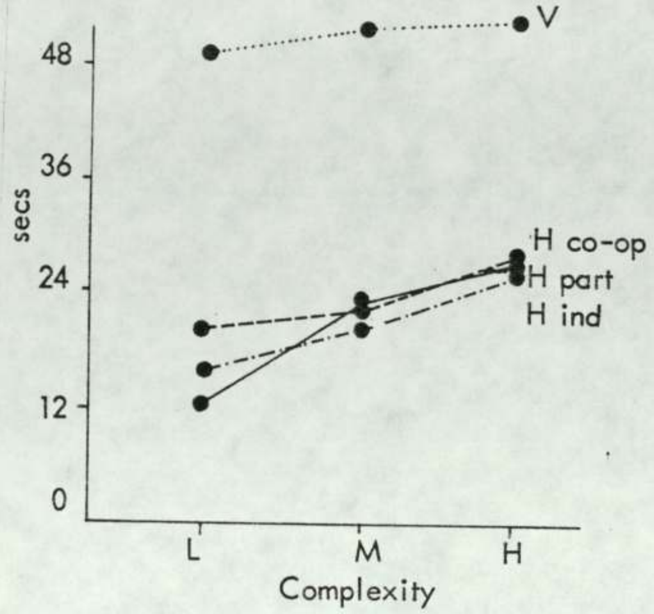
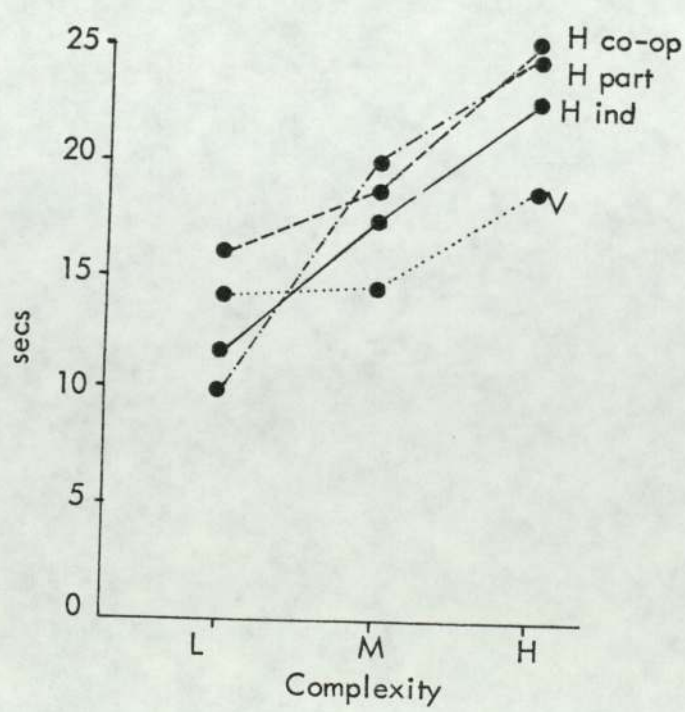


Fig. 3.4.6:

Av. process time

Fig. 3.4.7:

Av. label time



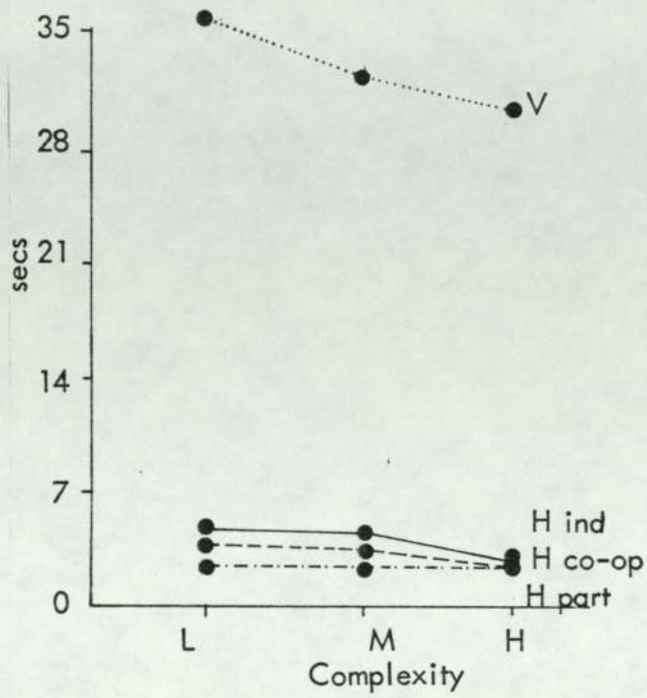
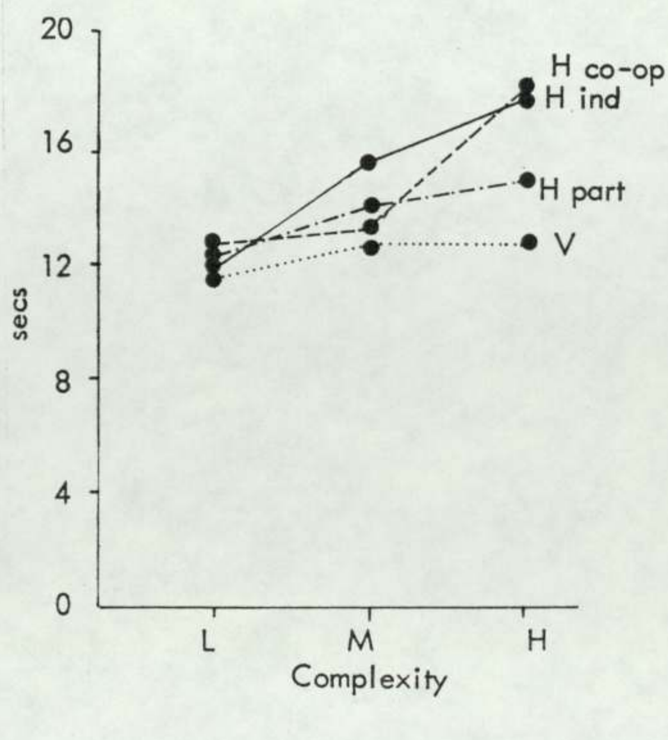


Fig. 3.4.8:

Av. communication time

Fig. 3.4.9:

Av. plot-report time



vertical response time on this measure does compare favourably with all horizontal measures. The plot-report time increases significantly with comp, $F\ (2,24) = 46.39$, $p<0.01$, and the difference between organisations, $F\ (3,12) = 8.66$, $p<0.01$, appears to increase with comp: low comp - not significant; medium comp - $F\ (3,36) = 8.23$, $p<0.01$; and at high comp - $F\ (3,36) = 32.02$, $p<0.01$. The vertical organisation is always superior on this measure (see Fig. 3.4.9).

b) <u>Accuracy Measures</u>

Although there is no significant organisation effect on the contacts plotted measure, it is seen from Fig. 3.4.10 that more contacts are plotted by the H. ind. teams, with very little difference between the other team organisations at medium and high comp levels. Performance of all teams falls with increases in comp, $F\ (2,24) = 29.04$, $p<0.01$. There are both comp effects, $F\ (2,24) = 15.05$, $p<0.01$, and organisation effects, $F\ (3,12) = 10.40$, $p<0.01$, on the wrong labels measure. H. part. has the worst performance at high and medium comp levels with vertical and H. co-op. generally giving the better performance measures. A Tukey Multiple Comparison of Means carried out on this data confirms this with the H. part. organisation differing significantly from the H. co-op. and vertical organisations (<0.01) and from the H. ind. organisation (<0.05).

The number of correct reports made and the number of report errors were significantly affected by comp: $F\ (2,24) = 65.47$, $p<0.01$, and $F\ (2,24) = 58.61$, $p<0.01$ respectively. However, no significant organisation effect is found on either measure. The H. part. organisation, whilst performing best on each measure at

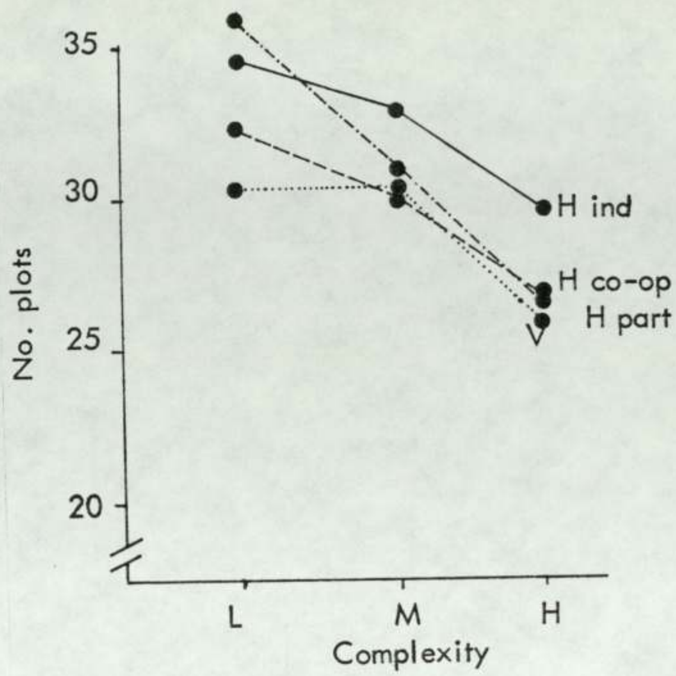
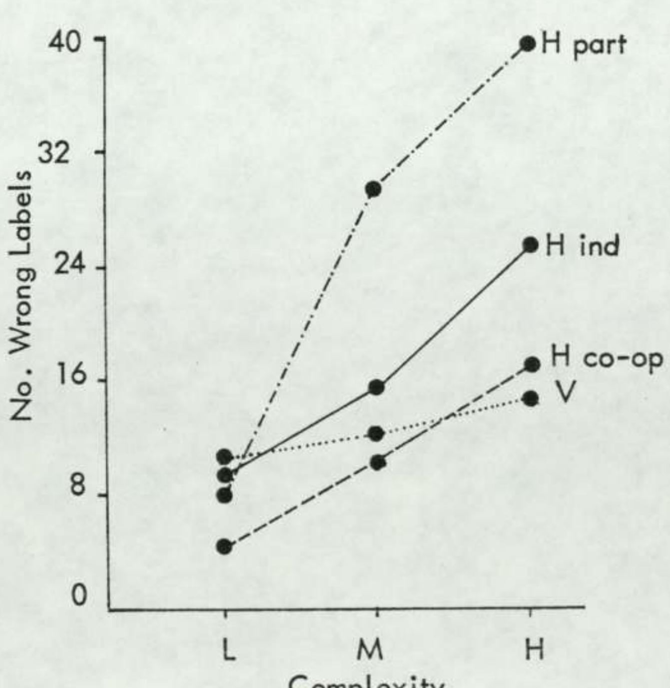


Fig. 3.4.10:

Av. no. contacts plotted

Fig. 3.4.11:

Av. no. wrong labels



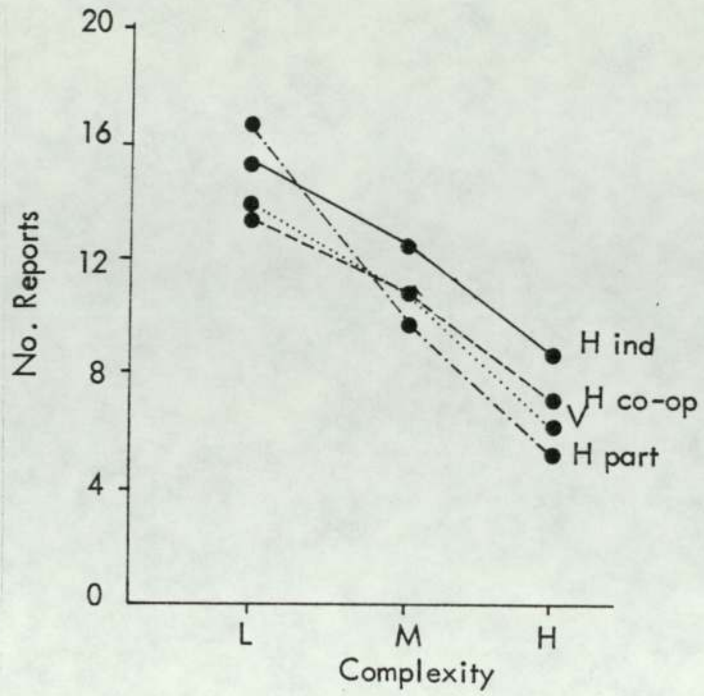
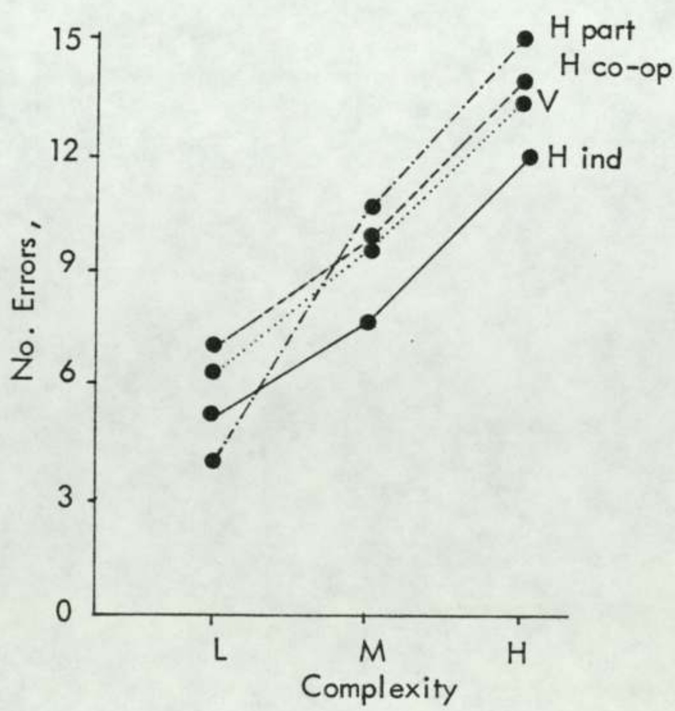


Fig. 3.4.12:

Av. no. correct reports

Fig. 3.4.13:

Av. no. report errors



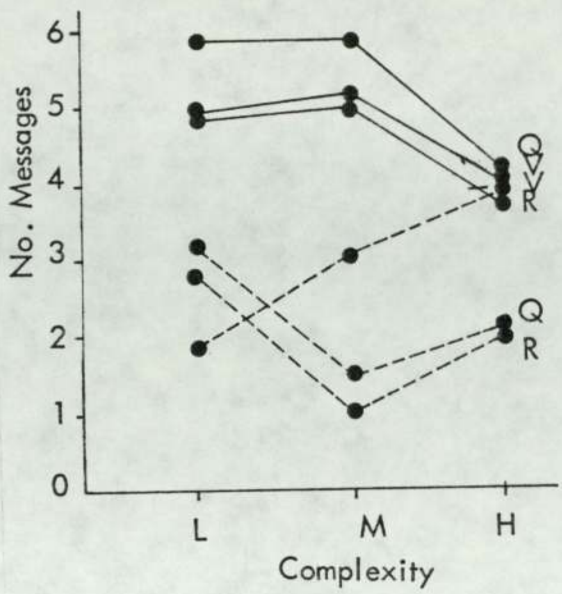


Fig. 3.4.14:

Av. amount of verbal communication

——— H. part
----- H. co-op
Q - direct questions
R - direct responses
V - voluntary messages

the low comp level (see Figs. 3.4.12. and 3.4.13), declines rapidly to become the most inferior organisation at medium and high comp levels on both measures. There is little difference between the other types of organisation, although the H. ind. organisation makes more correct reports and fewer errors. Because of the very small amount of false alarms and inaccurate reporting, these measures have been added to omissions to give a total error measure.

c) Verbal Communication Measures (H. part. and H. co-op only)

Although no significant differences are found between differently organised teams on any of the three verbal communication measures (direct questions, direct responses, and voluntary messages), it can be seen from Fig. 3.4.14 that there are more direct questions and responses in the H. part. organisation at all comp levels. Whilst the comp level does not affect the number of messages significantly, there appears to be a reduction at high comp level in the H. part. organisation, whilst the number of direct questions and responses increases at this level in the H. co-op condition. From low to medium comp level, there is little change in the H. part., but quite a substantial fall in direct messages in H. co-op. Similarly, whilst the number of voluntary messages fall at high comp with H. part., there is an increase through all levels of comp with H. co-op so that at high comp, there is almost the same amount of voluntary messages for both types of organisation. The amount of irrelevant messages was identical for both team organisations but, because of the extremely small amount, this measure has been discarded from this analysis.

DISCUSSION

The most notable aspect of the time measures is the difference between organisations on plot time. Even though the vertical organisation has longer response times than all three horizontal organisations, there are no significant differences. The consistently high H. co-op plot time and the steep increase with comp of the H. part. plot time are also noteworthy. This is reflected to a great extent in the waiting time measure, with steep increases in vertical and H. part. times at the high comp level, and H. co-op consistently high. The vertical process time differs significantly from all horizontal organisations, but this is due again to the communication time, much of which is unavoidable because of the extra operations involved in the vertical team organisation. With the other constituent of process time, the time taken to choose a label, the vertical organisation has the better response times, with the H. co-op and H. part organisations being inferior at medium and high comp levels. On response times, the relative consistency of the H. ind. teams contrasts with the disproportionate increases in the times of the other horizontal organisations at the higher comp levels. The vertical organisation, with its functional specialisation again has the best performance on plot-report times.

The number of contacts plotted falls with increases in complexity but, with its shorter response times, the H. ind. organisation is superior on this measure, although the high number of wrong labels chosen tends to detract from this performance. The H. part. is by far responsible for the most wrong labels, especially at the medium and high comp levels. One must assume that the need to co-ordinate over tracks crossing between sectors, with only a partial display to aid them, made for overloading of operators in this condition. This also is evident from the report errors of this organisation - inaccurate reports, false alarms, and omissions - all of which increase as comp rises. With the number of correct reports and report errors, the H. co-op organisation is consistently inferior to H. ind.

There is more verbal communication, as would be expected with the H. part. organisation, but it is interesting to note the decline at high comp of direct and voluntary messages. Perhaps, as operators become overloaded, they cannot formulate relevant and helpful questions, whilst their capacity to volunteer information becomes restricted. The opposite seems to be true of the H. co-op teams who, at high comp, take advantage of their full display (both operators have an identical display), with most questions asking for confirmation. Similarly, the amount of volunteered messages increases with load.

Three main findings arise from this experiment. Firstly, the increase in complexity through tracks crossing between sectors diminishes the superiority previously found in the horizontal organisation over the vertical. Secondly, the partial display of the H. part organisation, far from reducing 'clutter' and making the task easier for the operator, imposed co-ordination needs which, for the unskilled operator at least, resulted in overloading. Finally, it would appear from a comparison of H. ind. and H. co-op time and accuracy measures that the communication inherent in the latter organisation did not serve any useful purpose, but merely interfered with the performance of the task.

EXPERIMENT 4 (a)

To investigate the effects of practice on this task, the vertical organisation was repeated along with the best of the three horizontal organisations from Experiment 4. On the basis of the shortest average plot time and the highest average number of correct reports made at the high comp level, the horizontal independent (H. ind.) organisation was chosen.

METHOD

Three teams from the vertical organisation and three from H. ind. in Experiment 4 returned after approximately one month to perform the same experiment with the same task - the one other team from each condition in Experiment 4 was unavailable. Task complexity levels were identical (see Fig. 3.4.2) and a split-plot factorial design with repeated measures as in Fig. 3.4.15 was used.

		Complexity		
		Low	Medium	High
Session 1	Vertical	$T_1 - T_3$	$T_1 - T_3$	$T_1 - T_3$
	H. ind.	$T_4 - T_6$	$T_4 - T_6$	$T_4 - T_6$
Session 2	Vertical	$T_1 - T_3$	$T_1 - T_3$	$T_1 - T_3$
	H. ind.	$T_4 - T_6$	$T_4 - T_6$	$T_4 - T_6$

Fig. 3.4.15: Experimental Conditions (T denotes team)

A practice period was again used prior to the experimental period. Performance measures were as in Experiment 4, with the exception of the verbal communication measures which were only applicable to the former H. part. and H. co-op forms of team organisation.

RESULTS

a) Time Measures

The average plot time for both organisations falls at all comp levels over sessions but the difference is not significant (see Fig. 3.4.16). The horizontal organisation retains its superiority, as is also the case on wait and process times, differing significantly, $F(1,4) = 69.8$, $p < 0.01$, from vertical in the latter. However, investigation of the session/organisation interaction, $F(1,4) = 35.01$, $p < 0.01$, shows a relative improvement in the vertical organisation on Session 2, $F(1,8) = 201$, $p < 0.01$ and $F(1,8) = 53.97$, $p < 0.01$ (see Appendix XI for all statistical analyses). This is reflected in the average communication time (see Fig. 3.4.20) where the vertical organisation improves over sessions against the horizontal, $F(1,8) = 131.65$, $p < 0.01$ and $F(1,8) = 44.51$, $p < 0.01$. The horizontal organisation time hardly varies between sessions. The vertical organisation retains its superiority on labelling time, although this is not significant, except at the high comp level, $F(1,12) = 4.77$, $p < 0.05$. Labelling times do fall significantly over sessions, $F(1,8) = 31.81$, $p < 0.01$, but there is no overall organisation/session effect. On plot-report time, whilst the horizontal structure is still significantly inferior, $F(1,4) = 21.43$, $p < 0.01$, both types of organisation improve over sessions, $F(1,4) = 19.41$, $p < 0.05$. Again vertical performs relatively better as comp increases: medium comp, $F(1,12) = 5.53$, $p < 0.05$; high comp, $F(1,12) = 49.7$, $p < 0.01$.

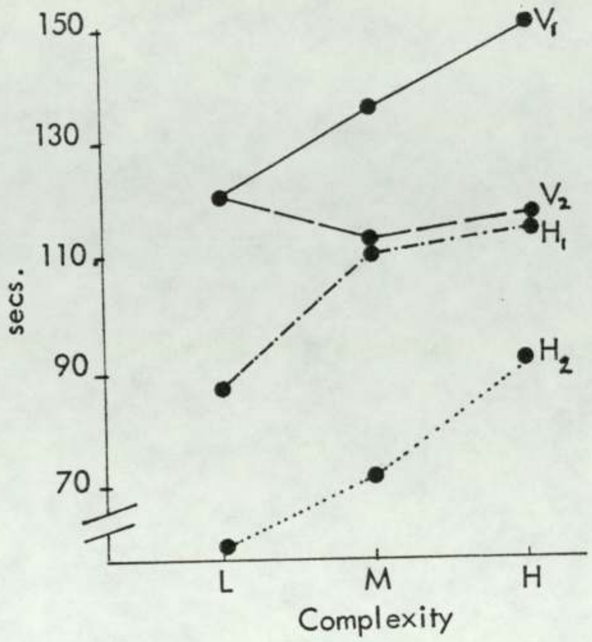


Fig. 3.4.16:

Av. plot time

1 = Session 1

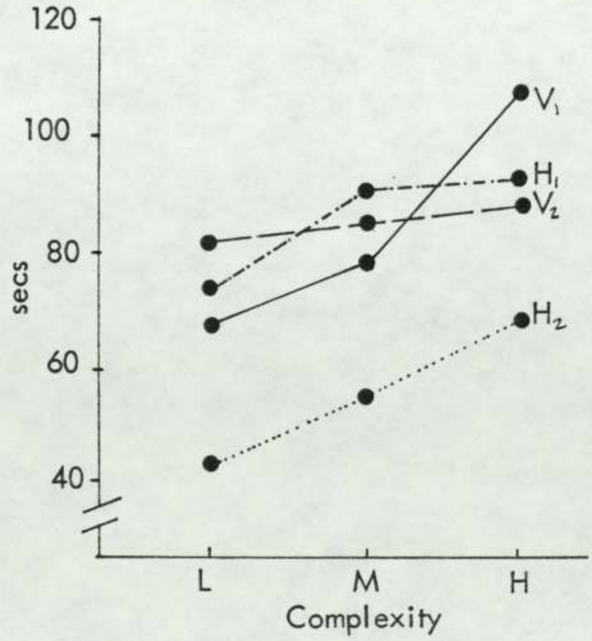
2 = Session 2

V = Vertical organisation

H = Horizontal organisation

Fig. 3.4.17:

Av. waiting time



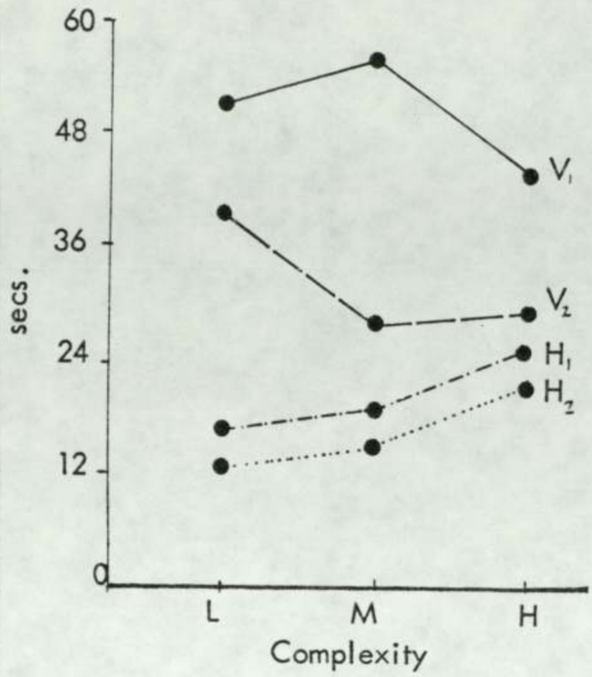
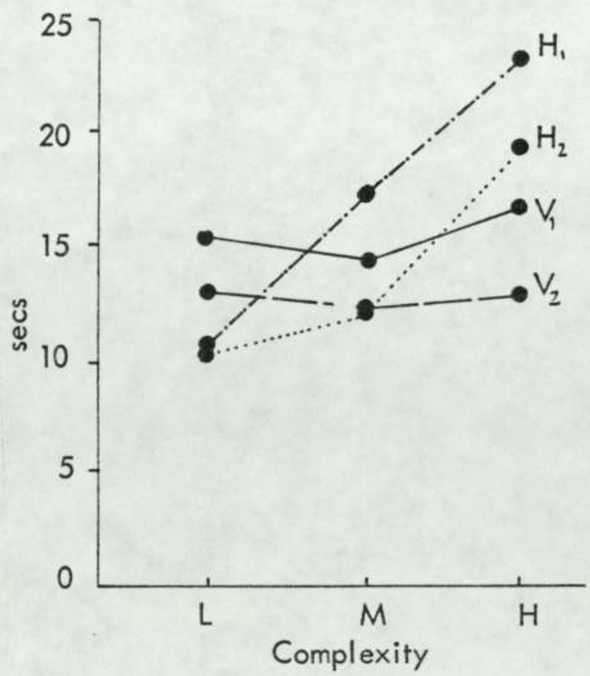


Fig. 3.4.18:

Av. process time

Fig. 3.4.19:

Av. label time



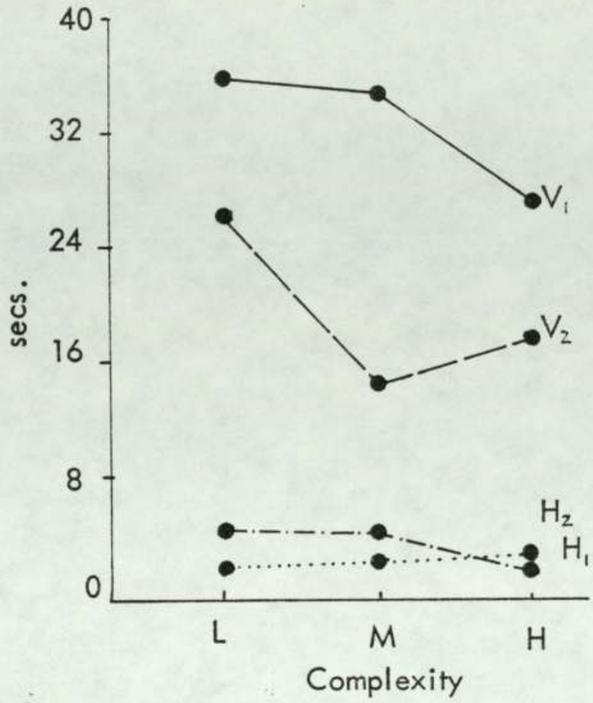
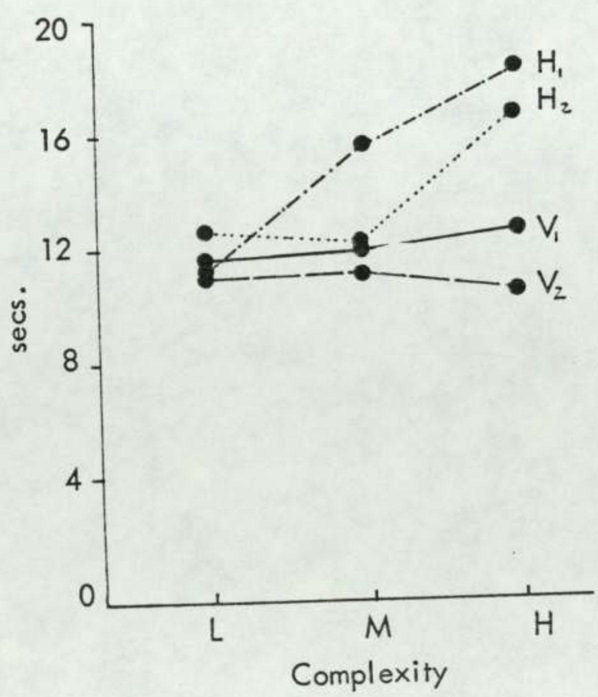


Fig. 3.4.20:

Av. communication time

Fig. 3.4.21:

Av. plot-report time



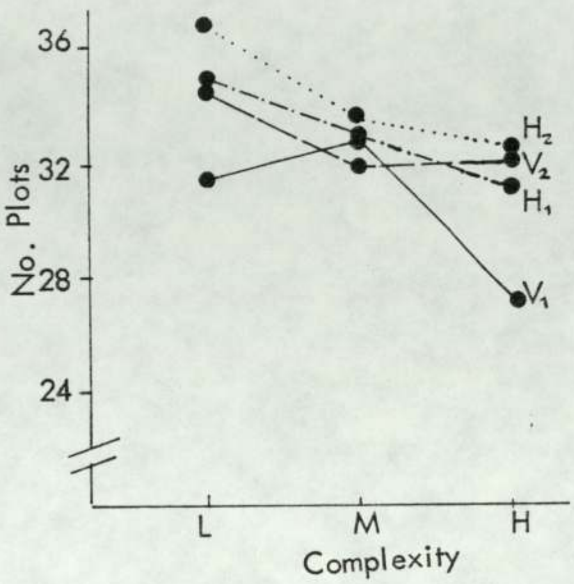
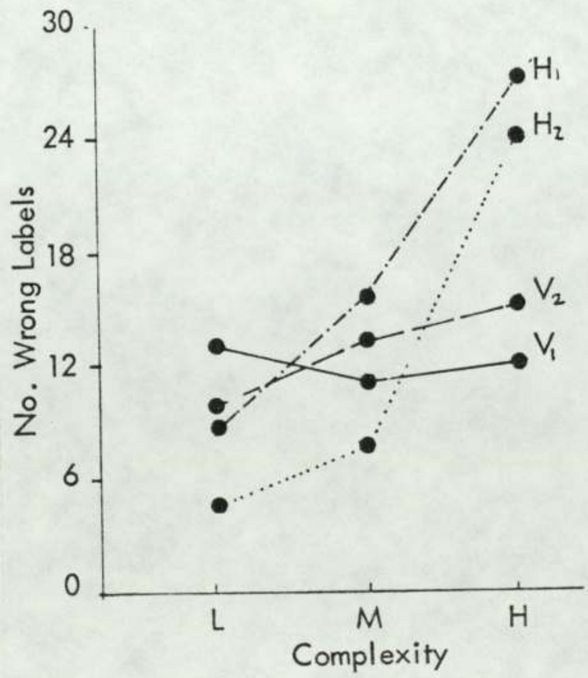


Fig. 3.4.22:

Av. no. contacts plotted

Fig. 3.4.23:

Av. no. wrong labels



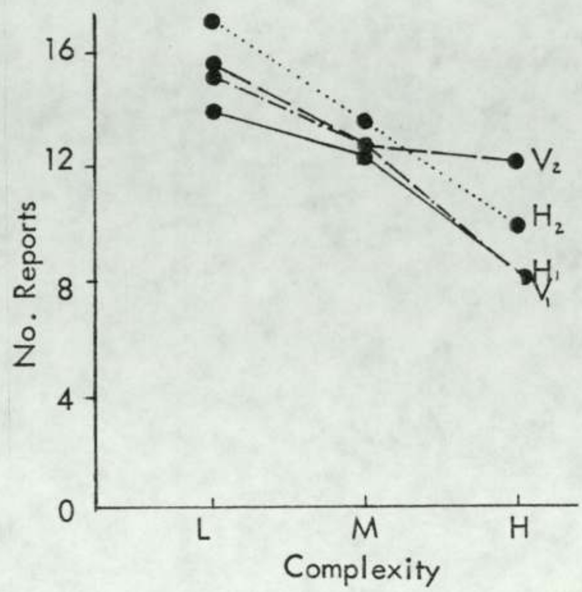
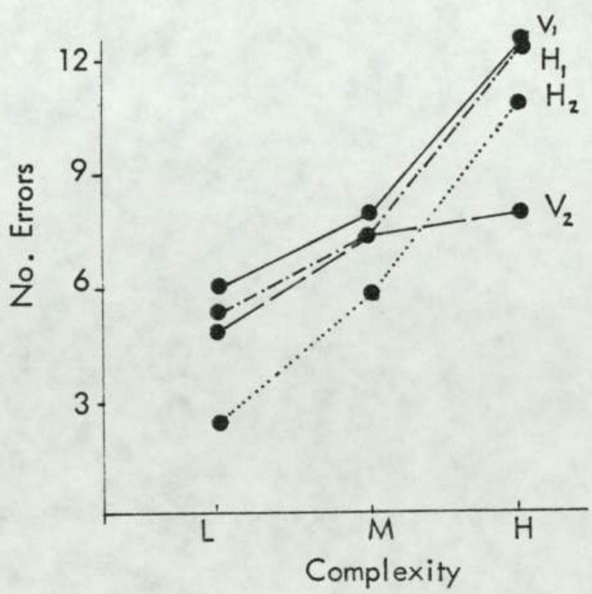


Fig. 3.4.24:

Av. no. correct reports

Fig. 3.4.25:

Av. no. report errors



b) Accuracy Measures

Both team organisations plot more contacts on the second session but only comp significantly affects performance (see Fig. 3.4.22), $F(2,8) = 11.24$, $p<0.01$. This is also the case with the number of correct reports (see Fig. 3.4.24), $F(2,8) = 20.74$, $p<0.01$, but here the vertical organisation is the better performer at high complexity.

Fewer report errors were made by the vertical organisation at high comp in Session 2 (see Fig. 3.4.25) but again organisations do not differ significantly. Only increases in comp lead to more errors, $F(2,8) = 19.5$, $p<0.01$. The horizontal organisation chooses fewer wrong labels in Session 2 but is still inferior to the vertical at high complexity.

DISCUSSION

Both types of team organisation had lower response times on the second session. As they kept abreast more of contact presentation so waiting time fell, but it is on process time that the only session effects are found. Here, a 30% improvement in performance at high comp level is made by the vertical organisation. Labelling time does not differ significantly, and it can be seen that this improvement is mainly due to the reduced communication time. Vertical operators appear to have become more practiced in co-ordination between the identification and plotting tasks.

Better response times make for more contacts plotted, although this is again accompanied by a high proportion of wrong labels with the horizontal organisation. More correct reports are made, and less report errors, by all teams.

Overall, then, a practice effect is evident but, apart from the improvement in vertical communication time, there is no significant change in the relative superiority, however reduced, of the horizontal organisation.

3.5

EXPERIMENT 5: The effect of increasing the number of required responses on teams organised in vertical and horizontal structures

Previous experiments (Experiments 2, 3, 4, 4 (a)) have varied the complexity of a computer-assisted task in order to investigate the effect on teams organised in vertical and horizontal modes. When presentation rate (Experiment 2) and the number of alternative tracks (Experiment 3) were increased, the advantages of the horizontal organisation in terms of response times and various accuracy measures were evident. However when co-ordination needs were increased, with tracks crossing between sectors (Experiment 4) the significant differences between vertical and horizontal organisations were not found, although horizontal performance was usually better than that of the vertical organisation. Overloading of the first vertical operator at high load levels often acted to the detriment of performance, whilst the second operator, responsible for plotting and reporting on contacts, could often have been given extra work. Operators working in horizontal structure, meanwhile, had to share their time between identification, plotting, and reporting.

The following experiment increases the reporting requirement of the task by introducing the 'status report'. As well as reporting verbally, as before, on changes in track movements, operators are required to periodically complete (by using their keyboard) a report showing the state of affairs at that time. No extra time is allowed to complete this report, i.e. new contacts continue to be presented for identification. Consequently, an extra task is given to the second vertical operator who has now to verbally report and status report on all tracks, and the horizontal operators have now an extra task to compete for their time - sharing resources. Two types of horizontal organisation are considered: (i) where each operator continues to be responsible for his own tracks, and (ii) where one operator, through consultation with the other, completes a status report for all tracks. It would be expected that the effect of introducing this extra reporting requirement would have a more detrimental effect on the performances of operators working in the horizontal structure than on those working in the vertical structure with its functionally specialised operators.

METHOD

a) Task and Apparatus

The experimental task again utilized the computer-aided simulation used in Experiments 2, 3 and 4 and described in detail in Chapter 3.2. Teams of two operators were presented with contact information which they processed by following a question-and-answer routine. Identification and plotting of contacts preceded the verbal reporting of any changes in the progression of tracks:- course and speed changes, and tracks crossing between the sectors of the two operators working in horizontal. The tracks used in this experiment are shown in Appendix VI. However, an additional reporting task was included, whereby at regular intervals throughout the experimental session, teams were required to complete a status report. This is a call - signalled by the words 'Status Report Due Now' on the printer - for up-to-date information on the position and track movements of

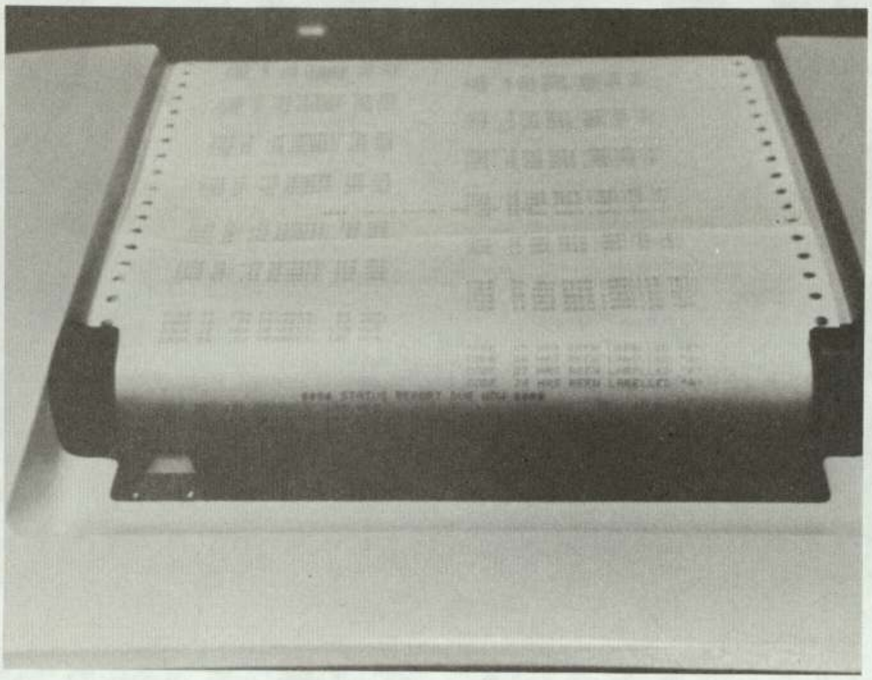


Fig. 3.5.1: Call for a Status Report

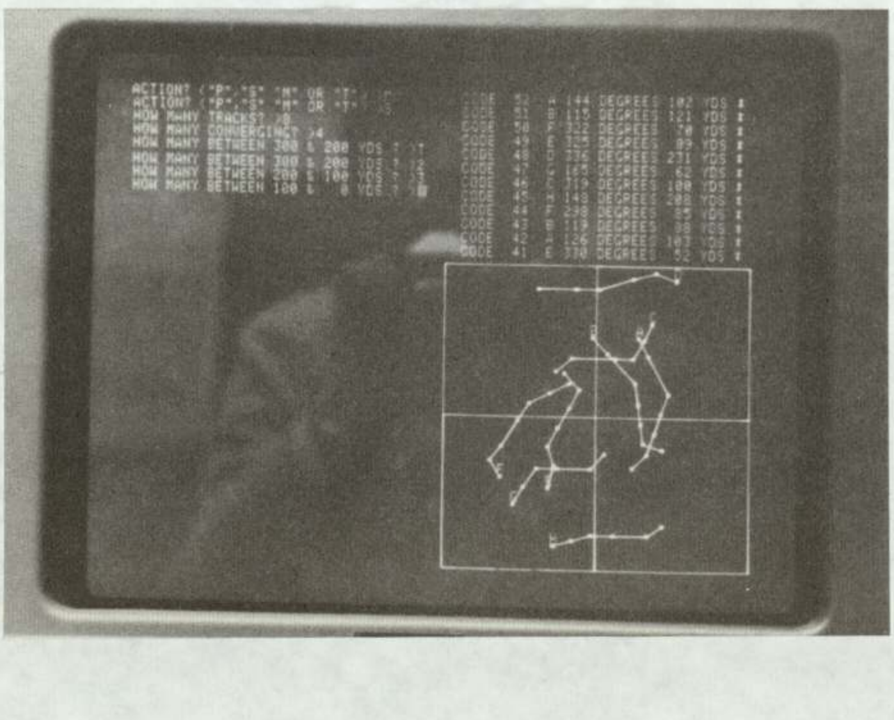


Fig. 3.5.2: The Status Report - Question-and-Answer Routine

surrounding vessels. The photograph in Fig. 3.5.1 shows the call for a status report with an example taken from the input to an operator working in a vertical team arrangement.

Subjects were instructed to commence a status report as soon as possible after receiving the call on the printer. In Appendix II can be found the additional instructions given to subjects to complete a status report. It can be seen that the pressing of the S key on the V.D.U. keyboard will bring forth a question-and-answer routine which the operator completes using the map and/or table facility as an aid. The photograph in Fig. 3.5.2 shows the question-and-answer routine with an example taken from a horizontal independent (H. ind) team organisation (see below for details on different organisations used).

b) <u>Subjects, Design and Procedure</u>

Twelve teams of two subjects were used. All were volunteers, paid for their services, drawn from the student population at the University. They were all experienced in the type of task, having taken part in Experiment 4 (see Chapter 3.4). The twelve teams were assigned, according to previous experience, to one of three types of team organisation:-

(i) Vertical:- one operator was responsible for labelling all contact information for all tracks, with the second operator plotting and reporting on contacts for all tracks. The second operator, then, besides verbal reporting, was responsible for completing the status report (see Appendix II).

(ii) Horizontal co-operative (H. co-op):- each operator labelled, plotted and reported verbally on contacts referring to tracks in their own area of responsibility. However, only one operator could status report at one time. Consequently, operators had first to decide who was to carry out the report and then, through consultation with each other, a status report relating to a summation of their individual track information was to be produced. Both operators had a map at their disposal showing all their own plotted contacts as well as those of their fellow team member, but the information on their table facility referred only to their own tracks.

(iii) Horizontal independent (H. ind):- as in (ii) above but operators performed their own status reports referring only to the tracks appearing in their own area of responsibility.

Only one comp level was used as follows:

Presentation rate	4 per 90 seconds
No. tracks	8
No. crossovers	4
No. contacts	72
No. changes	40
No. status reports	5

Fig. 3.5.3: Task Complexity

The presentation rate and number of tracks are identical to the high comp level of Experiment 4. However, the five status reports, with no additional time allowed for their completion, impose an additional comp factor.

Two identical experimental sessions of approximately 27 minutes were used with a 20-minute rest interval between them, as shown in Fig. 3.5.4.

Prior to these, all teams completed a practice session.

		Session	
		1	2
Organisation	Vertical	T_1 - T_4	T_1 - T_4
	H. co-op	T_5 - T_8	T_5 - T_8
	H. ind.	T_9 - T_{12}	T_9 - T_{12}

Fig. 3.5.4: Experimental Conditions (T denotes team)

c) Performance Measures

These were essentially the same as those taken in Experiments 2, 3 and 4. The plot time and its constituent waiting and process times were again time measures, as well as the constituents of process time, the time to choose a label and the communication time. The time elapsing between plot and report was again taken but an additional time measure was the time taken to perform a status report. This latter measure did not include waiting time, being the time spent actually completing the report. For H. ind. the longest of the two times was used.

In addition to the usual accuracy measures of the number of contacts plotted, the number of wrong labels, and the number of correct reports and report errors, there were two additional accuracy measures relating to the status report: (i) the difference between actual state of affairs and what appeared on the operator's screen and; (ii) the difference between the screen situation and the interpretation of the operator. It was hoped that the first of these measures would give an indication of how much teams kept up-to-date on plotting, and that the second measure would show how different team organisations affected interpretation of the screen situation. To arrive at these measures the appropriate amount of points was given for each deviation from the appropriate measure - the higher the score the worse the performance.

e.g.	Screen		Operator	Points deviation
	Converging tracks	4	3	1
	300 - 200 yards	3	2	1
	200 - 100 yards	2	2	0
	100 - 0 yards	4	2	2
			Total score:	4

RESULTS

a) Time Measures

The two forms of horizontal organisation have significantly better plotting times (<0.01) than the vertical organisation (see Tukey Multiple Comparison of Means, and all other statistical analyses in Appendix XII). However all types of organisation improve significantly over sessions, $F\ (1,9) = 164.77$, $p<0.01$. (See Fig. 3.5.5). There is also a significant effect on waiting time over sessions, $F\ (1,9) = 40.74$, $p<0.01$, but no significant differences exist between organisations on this measure. With process time, there are significant differences between organisations, $F\ (2,9) = 62.63$, $p<0.01$, between sessions, $F\ (1,9) = 20.72$, $p<0.01$, and a session/organisation interaction, $F\ (2,9) = 12.54$, $p<0.01$. A simple main effects reveals highly significant F values at both Session 1 and at Session 2: $F\ (2,18) = 676.56$, $p<0.01$ and $F\ (2,18) = 358.72$, $p<0.01$. This is due to the much improved performance of the vertical organisation against the horizontal as seen in Fig. 3.5.7. The effects on process time are

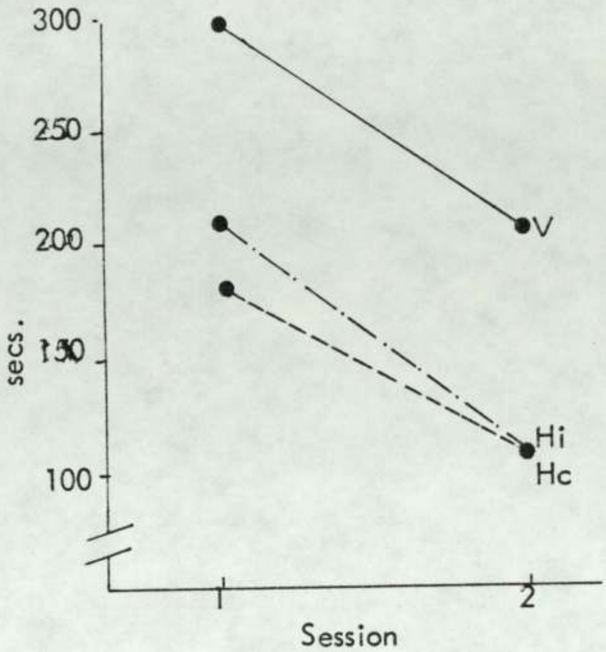
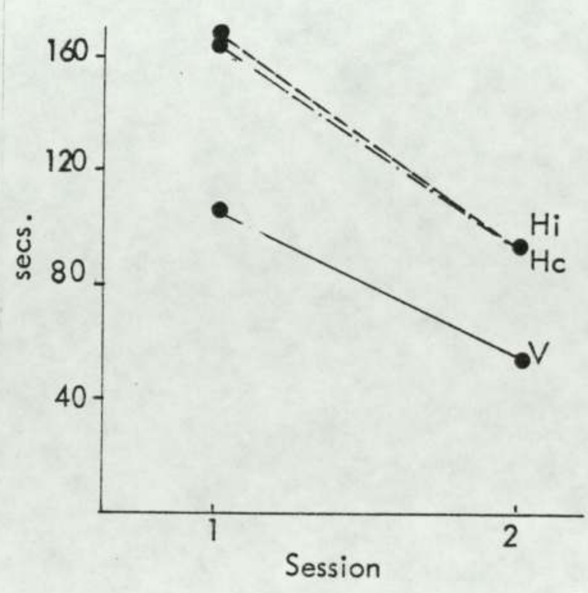


Fig. 3.5.5:

Av. plot time

Fig. 3.5.6:

Av. waiting time



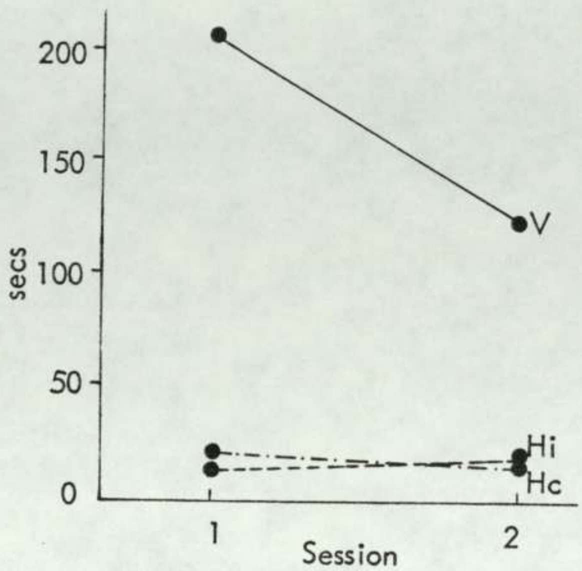
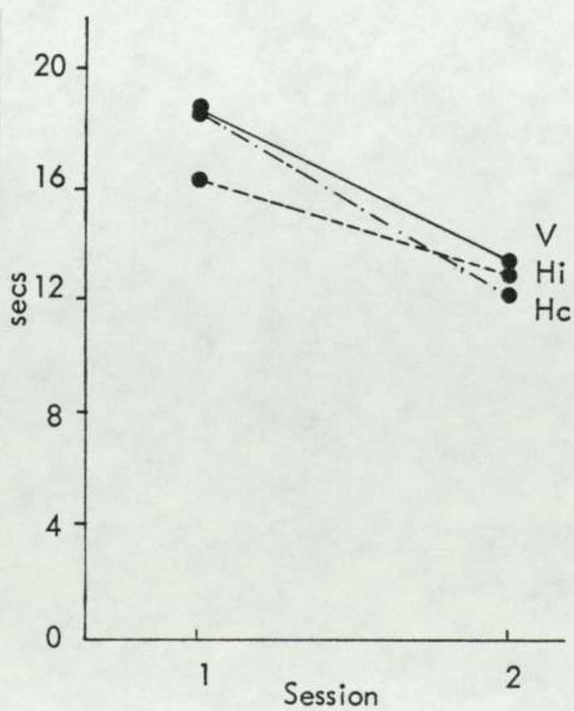


Fig. 3.5.7:

Av. process time

Fig. 3.5.8:

Av. label time



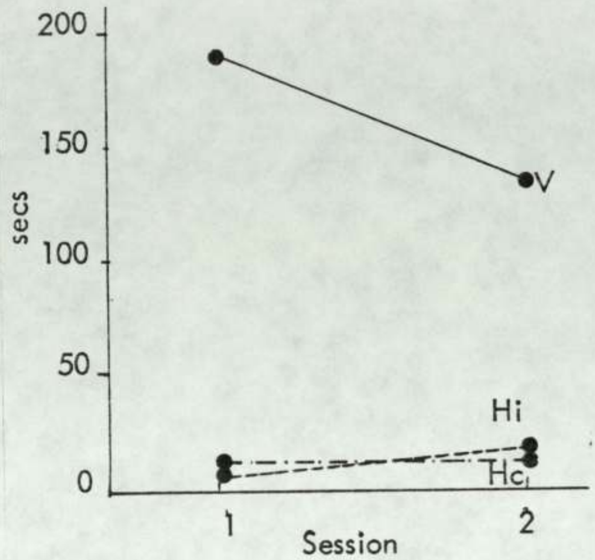
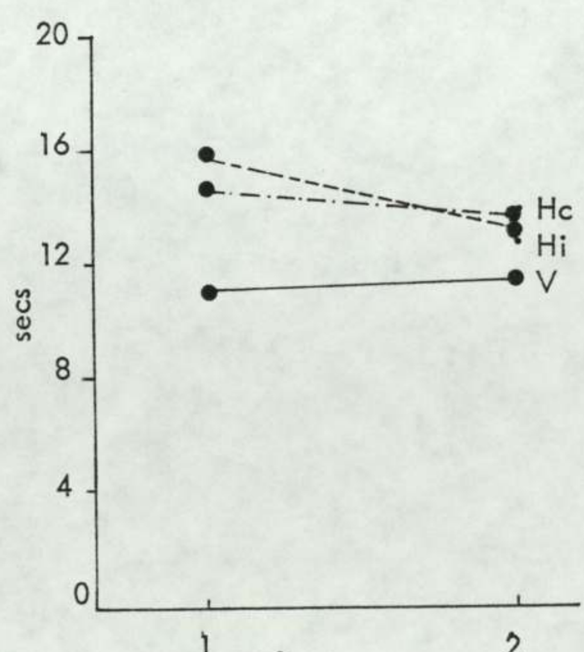


Fig. 3.5.9:

Av. communication time

Fig. 3.5.10:

Av. plot-report time



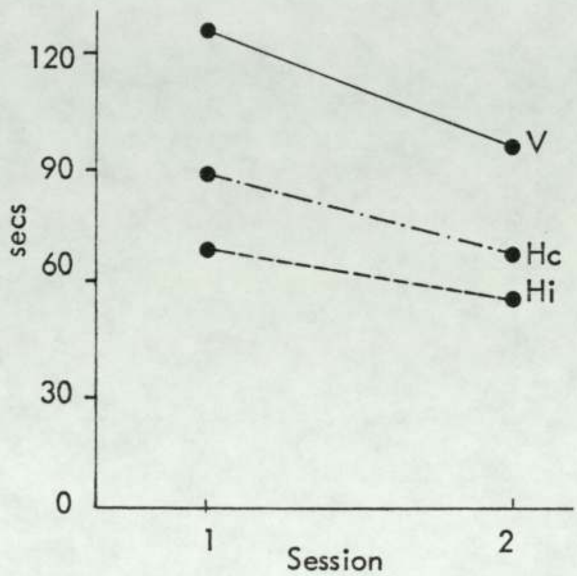
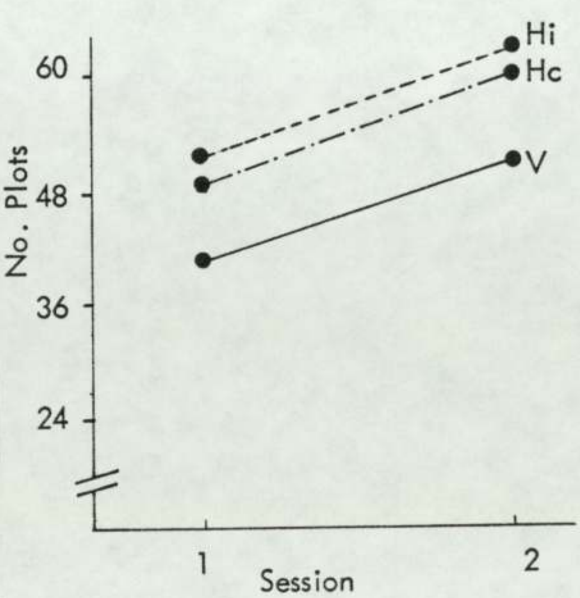


Fig. 3.5.11:

Av. pass time - Status Report

Fig. 3.5.12:

Av. no. contacts plotted



largely reflected in one of its constituent elements, communication time, where there is an organisation effect, $F (2,9) = 13.3$, $p<0.01$, and an interaction, $F (2,9) = 13.93$, $p<0.01$. Fig. 3.5.9 demonstrates the improvement over sessions of the vertical organisation with the simple main effects showing $F (2,18) = 754.97$, $p<0.01$ at Session 1 and $F (2,18) = 400.46$, $p<0.01$ at Session 2. Labelling time improves over sessions, $F (1,9) = 71.29$, $p<0.01$, with the vertical structure always the slower, but the difference is not significant.

No significant differences between organisations or between sessions are found on the time between plotting and verbal reporting although, as can be seen from Fig. 3.5.10, the vertical organisation always has the lower response time. On the final time measure, the time taken to complete a status report, there is a significant session effect, $F (1,9) = 71.95$, $p<0.01$ with all forms of organisation improving over sessions (see Fig. 3.5.11). However, a Tukey Multiple Comparison of Means carried out on the significant organisation effect, $F (2,9) = 6.05$, $p<0.05$, shows the H. ind. organisation to be faster than the H. co-op (<0.01) and both horizontal organisations to be significantly faster than the vertical (<0.01).

b) Accuracy Measures

All types of organisation plot more contacts on the second session, $F (1,9) = 154.01$, $p<0.01$, with H. ind. being superior and vertical inferior on both sessions (see Fig. 3.5.12). A significant session effect is also found on the number of correct reports, $F (1,9) = 61.33$, $p<0.01$, and on the number of report errors, $F (1,9) = 45.55$, $p<0.01$, with all organisations improving

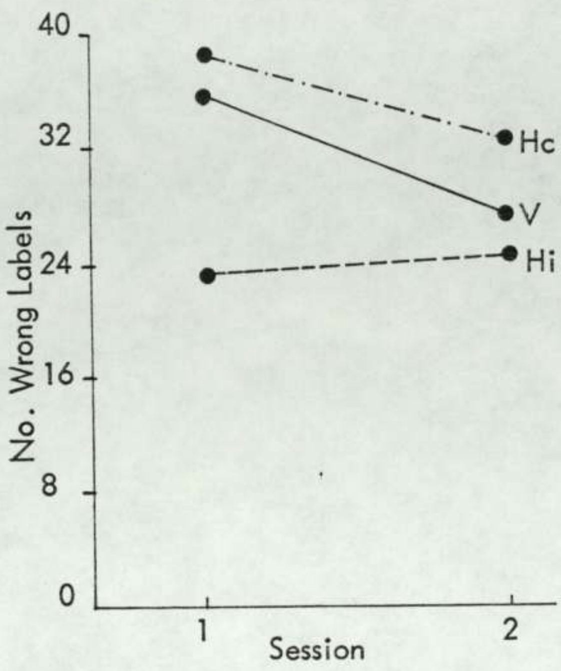
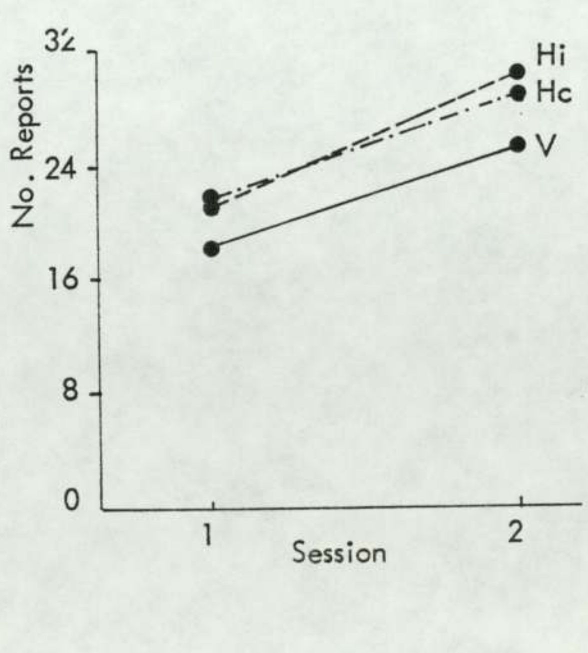


Fig. 3.5.13:

Av. no. wrong labels

Fig. 3.5.14:

Av. no. correct reports



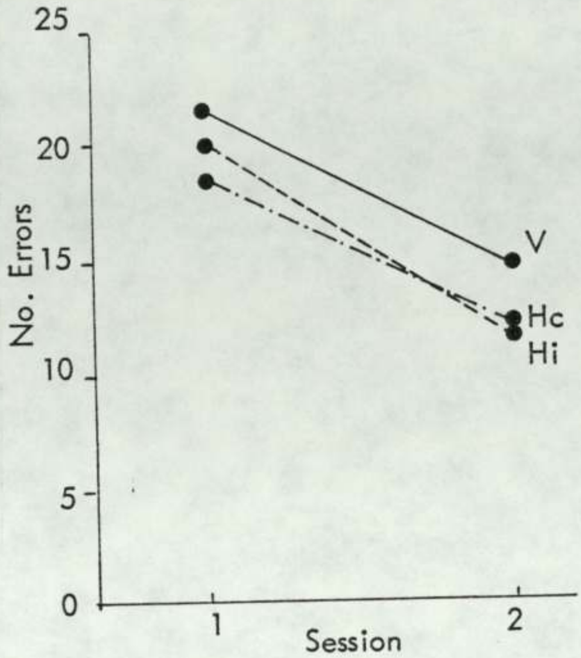
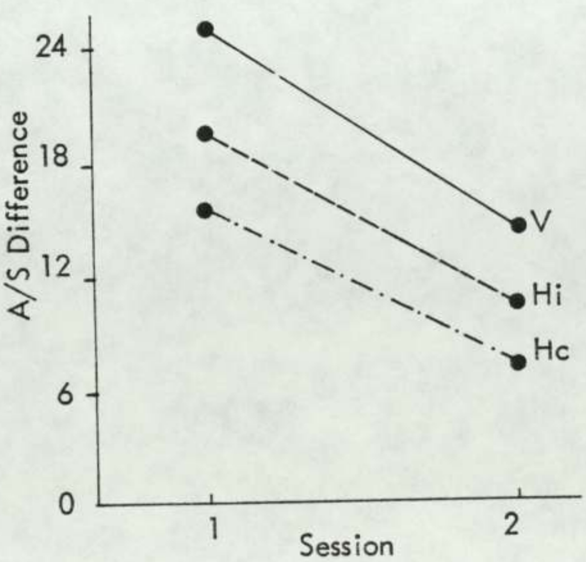


Fig. 3.5.15:

Av. no. report errors

Fig. 3.5.16:

SR Error - Actual/ Screen



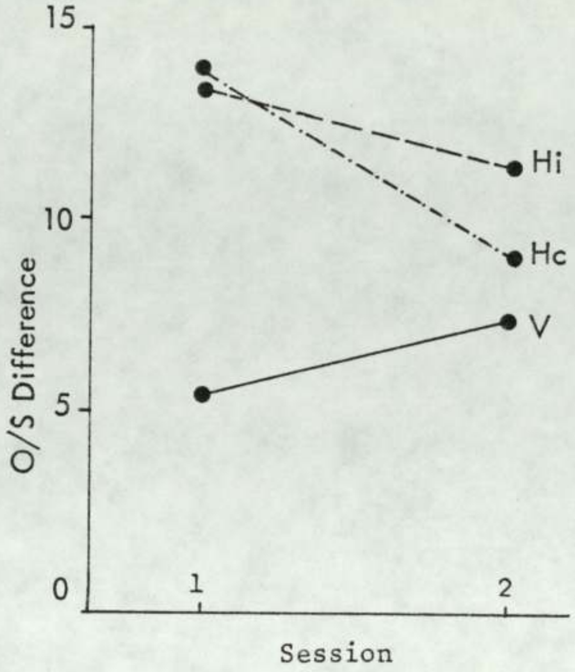


Fig. 3.5.17:

SR Error - Operator/
Screen

on Session 2. No significant differences exist between organisations on these measures but H. ind. usually has the better performances (see Figs. 3.5.14 and 3.5.15). The number of wrong labels generally falls over sessions but organisations do not differ significantly.

There were no significant differences between organisations on the two status report error measures. However, the Actual/ Screen score did improve over sessions, $F\ (1,9) = 75.87$, $p<0.01$. H. co-op was the best performer on these two measures, but, although not significantly, the vertical organisation is superior on the Screen/Operator measure (see Fig. 3.5.17).

DISCUSSION

The vertical organisation is significantly inferior to the two horizontal organisations over both sessions on overall plot time. However, within this measure, the wait time and the process time demonstrate the different working methods of the vertical and horizontal organisations. When a status report became due, the horizontal operators usually completed processing their present contact and then started the status report. Meanwhile, other contacts continued to appear on the printer. The first vertical operator, unconcerned with the status report could continue to process these, but their neglect by the horizontal operators made for the high amount of waiting time. Conversely, the process time for vertical operators is high because contacts, already identified, 'queued' for plotting whilst the second operator completed the status report. This is further shown in the communication measure. All response times improved over sessions but the only interaction effect is on the afore-mentioned communication measure with a disproportionate improvement in performance for the vertical organisation on the second session. On time taken to complete the status report, the vertical organisation is highest with the H. ind. lowest. However, the latter is for only half the tracks and has, theoretically, to be summated at a later stage.

Longer plot times again make for less contacts plotted and here the H. ind. has the highest number of plots. The vertical organisation, with less plots, has fewer correct reports and more report errors, due almost entirely to omissions. All organisations improve on these measures over sessions, there being very little difference between the two horizontal organisations.

The two status report error measures show that, whilst the vertical organisation has a more inaccurate screen display due to its slower rate of plotting, the interpretation of the screen display (the Screen/Operator measure) is more accurate with this organisation. Indeed, the least accurate interpretation is performed by the H. ind. organisation which completes the status report in the fastest time. Depending on the criterion adopted, it is the H. co-op organisation which appears to include the most up-to-date screen display, with an acceptable interpretation in an acceptable time. This seems to be the result of practice when, on Session 2, operators have decided on the strategy to employ in performing the status report.

Whilst the addition of an extra response requirement does negatively affect horizontal performance, it also affects the performance of the vertical organisation. With eight tracks to consider, the second vertical operator cannot complete a status report as quickly as the horizontal operators who divide their responsibilities. Consequently, the process time of contacts is increased leading to higher plot times and so less plots. Although accuracy on status reporting is superior to the horizontal organisation, other accuracy measures are consequently inferior. Within the horizontal organisations, response times and verbal reporting performance are very similar. However, for performance on status reporting, the H. co-op organisation appears to be superior. Once operators have practised status reporting procedures, it seems that a joint effort eliminates various inaccuracies, e.g. those arising from a double-counting of a track when it has crossed from one operator to the other.

The additional complexity arising from the extra task of status reporting increased the overall task complexity for all teams, regardless of their mode of organisation. A further increase in complexity arose from the low intra-task organisation between the status report and the other plotting and verbal reporting tasks. Inter-task organisation was necessary, as in the other experiments (see Chapter 3.1., 3.2., 3.3., and 3.4), in the vertical organisation, but this also occurred in the horizontal organisation, particularly when the two operators were required to co-operate in producing a single status report. These factors contributed to a disproportional increase in the complexity of the tasks of the horizontal operators relative to the increase in the complexity of the tasks of the vertical operators. Consequently, horizontal plot times are again significantly superior to the vertical, but this difference is not as emphatic as in earlier studies.

CHAPTER 4. CONCLUSIONS

The series of experiments described in Chapter 3 has investigated the effects on the performance of two-man teams of various types and levels of task demands. Of particular interest has been the ways in which the total task complexity imposed on the system can be modified by the organisation of the team, i.e. the distribution, or allocation, of task demands between operators, in order to reduce the load imposed on the system. A comparison of the performance of teams organised in a vertical, or functionally-specialised manner, with teams organised horizontally, where individual operators perform all tasks but share the total task complexity, has been the main aim of the research.

Throughout the experiments, the dependency relationships and temporal relations between tasks has remained invariant, with identification, plotting, and reporting tasks being necessarily performed sequentially in that order. Tasks have been of a divisible nature so that a genuine division of labour has been possible between team members - a comparison between methods of team organisation has thus been made possible. It is the complexity, or information-processing demands, of tasks which has been varied, with changes on such task dimensions as input presentation rate and the number of different types of responses required. Total task complexity has also been affected by the method of team organisation, and the level of task organisation. The vertical team organisation, for example, due to the inherent interaction requirements between operators, always has a degree of inter-task organisation which adds to the complexity of the team tasks. Alternatively, the horizontal team organisation may have varying degrees of inter-task organisation, depending on the nature of the task to be performed. Intra-task organisation, i.e. the relationships between the tasks performed by a single operator, is also of importance, especially to the horizontal organisation, since the higher the level of intra-task organisation, the lower the individual operator workload.

As total complexity has been increased, the performance of teams in terms of the various speed and accuracy measures, has tended to fall regardless of the method of team organisation employed. Results have shown, though, that both methods of team organisation have their advantages, and that this depends to a great extent on the nature of the task demands imposed. Generally, a horizontal team organisation is superior when input complexity is high, since the first vertical operator may become overloaded and the second operator whose inputs are the outputs from the first, would be underloaded because of the low amount of information received for processing. If a horizontal organisation were employed, inputs may be divided between the two operators, thus equalising the demands imposed on each position. However, this superiority tends to diminish if the complexity of individual tasks is so high that effective time-sharing between the different tasks is made impossible. This problem is aggravated when there is a low level of intra-task organisation. The performance of the horizontal team organisation also appears to decrease when some measure of inter-task organisation is necessary. Such interaction requirements reduce the benefits of autonomy usually afforded by this method of team organisation. Although a full account of experimental findings appears at the end of each experimental report in Chapter 3, the main conclusions are discussed below.

In the first experiment, there was a tendency for the vertical organisation to be superior at the high level of complexity in terms of plotting errors on the time-bearing plot. Errors made by the horizontal organisation were mainly errors of omission, primarily caused by the difficulties encountered in time-sharing between the construction of the time-bearing and local operations plots. These problems arose from a combination of the high level of complexity imposed by the motor demands of the tasks, e.g. the use of protractors and multi-point dividers, and the low level of intra-task organisation existing between them. The functional division of responsibilities in the vertical organisation precluded the need for such time-sharing. Furthermore, the presentation rate of contacts was such that the first vertical operator did not become excessively over-loaded, and only a low amount of inter-task organisation was necessary between vertical operators. Consequently, there were no relative advantages accruing from the autonomy of horizontal operation.

With computer assistance, intra-task organisation was higher in subsequent experiments, particularly between the identification and plotting tasks. Horizontal operators, after identifying and attaching a label to a contact, were able to plot it by simply pressing the appropriate key. The vertical organisation, however, could not take full advantage of such task integration because of the inter-task organisation between first (identification) and second (plot and report) operators. Indeed, throughout all the later experiments, this co-operative requirement between vertical operators added to the complexity of the team tasks and was a major contributor to overall response times. The latter were usually higher than those of the horizontal organisation and so, consequently, were the number of reporting errors of omission.

The horizontal superiority was most in evidence in the second and third experiments, when input complexity was high. In the former experiment, complexity was increased through increases in the presentation rate of contacts on four tracks for identification, i.e. low: 4 per 160 seconds; medium: 4 per 120 seconds; high: 4 per 80 seconds. This input could be divided between horizontal operators, but the first vertical operator became overloaded. Waiting time increased disproportionately with complexity as contacts queued for identification, and process time was also significantly higher than for the horizontal organisation because of the vertical inter-task organisation requirement. Longer response times led to a lower rate of plotting and a high number of reporting errors due to omissions. Horizontal operators were able to work independently, i.e. there was a low level of inter-task organisation. Also, the reporting task was of low complexity, due to the high degree of intra-task organisation between it and preceding tasks. Once a contact had been plotted, operators were required only to look at their plot - by pressing the appropriate key - and make simple verbal reports. Horizontal operators, then, did not experience to a great extent, the time-sharing problems so prevalent in the first experiment. Presentation rate was constant in the third experiment, being equal to the medium complexity condition of the second experiment. Input complexity was increased by increasing the number of tracks, i.e. 4, 6 and 8, so imposing greater discriminatory demands on operators. Once again, significantly superior response times were achieved by the horizontal operators. However, vertical waiting time improved relative to the second experiment, only rising disproportionately at the high level of complexity when the first operator had to discriminate between eight possible tracks. The high proportion of reporting errors of omission by the horizontal organisation did suggest that the higher discriminatory demands on operators had contributed to time-sharing problems, i.e. plotting at the expense of reporting.

Intra-task organisation remained the same in the fourth experiment with, for the vertical organisation, similar levels of task complexity. However, the team task was made more complex for horizontal operators by using a scenario where tracks crossed between the sectors of responsibility of the two operators. In this experiment, the horizontal organisation was varied in three ways, depending on whether verbal communication was allowed between operators, and on the type of display available to them: (i) full display with independence; (ii) full display with communication, and; (iii) partial display with communication. This was done to investigate whether the latter two conditions would be conducive to more effective horizontal team performance either through enabling more effective co-ordination of tracks moving across sectors, or by reducing 'clutter' on the display. This was not found to be so. All types of horizontal organisation suffered from problems of co-ordinating tracks and no significant differences in time and accuracy measures were found between them and the vertical organisation. Indeed the independent horizontal organisation performed more effectively of the three. The inter-task organisation introduced into the two interaction conditions appeared to be interfering rather than beneficial, with these teams producing higher response times with no corresponding increase in accuracy. Time spent in communicating appears to have reduced the time available for identification and plotting and this led to time-sharing problems with the reporting task.

The fifth, and final, experiment increased task complexity by requiring the completion of a status report in addition to, and concurrent with, the usual verbal reports. Horizontal operators, as well as the second vertical operator, now had an additional task to compete for their time-sharing resources. Furthermore, the status report had very little intra-task organisation with other tasks - operators completed a status report by using a question-and-answer routine on their graphics terminals in conjunction with the tabular listing of plotted contacts from which inferences on track movements were made. Two types of horizontal organisation were considered: (i) independent, where each operator carried out a status report only for tracks in their own area of responsibility, and; (ii) co-operative, where either operator, through co-operating with the other, completed a single status report for all tracks. All forms of team organisation produced longer plot times than in the equivalent condition in the fourth experiment, i.e. contacts on 8 tracks appearing at a rate of 4 per 90 seconds, because of the additional complexity caused by the extra task. The plot time of the vertical organisation was significantly inferior to those of the two horizontal organisations but this difference was not as emphatic as in previous studies. The difference was largely due to the different working methods used by the vertical and horizontal organisations when a status report became due. Horizontal operators usually completed the processing of their present contact before starting the status report. Meanwhile, other contacts continued to appear on the printer. The first vertical operator, unconcerned by the status report, could continue to process these but their neglect by the horizontal operators made for a high amount of waiting time. Conversely, the process time, the other constituent of plot time, was high for vertical operators because contacts, already identified and labelled, queued for plotting whilst the second operator completed the status report. Although accuracy on status reporting was superior to that of the horizontal organisations, other accuracy measures, e.g. omissions and number of contacts plotted, were consequently inferior. In spite of the level of inter-task organisation in the co-operative condition, there was very little difference between horizontal organisations on any of the time and accuracy measures. This was probably due to the development of effective status reporting procedures by interacting operators.

Experimental findings suggest, then, that for two-man teams, a horizontal team organisation will be superior to a vertical team organisation in the majority of cases, especially when input complexity is high. This superiority, though, tends to diminish when changes in task demands, e.g. an increase in inter-task organisation, a decrease in intra-task organisation, or an increase in the complexity of individual tasks, lead to an overall task complexity too high for effective time-sharing.

Such a conclusion can be tentatively advanced to describe related findings on divisible tasks in the literature. Of immediate relevance is the only study to compare vertical and horizontal team performance which was carried out by Lanzetta and Roby (1956 (b)) and described in Chapter 2.2. page 43. Using an air intercept task, they organised three-man teams so that, in the vertical condition, operators respectively: (i) monitored the position report and made the necessary moves on the board; (ii) identified aircraft as friendly or hostile, and; (iii) deployed the interceptor force. Horizontal operators performed all these tasks for their own areas of responsibility. There was a tendency for the vertical organisation to be superior at high levels of complexity, i.e. specialisation appeared to be relatively more effective when task load was heavy. The authors attempted to explain this finding in terms of the characteristics of the tasks to be performed. The monitoring and tracking task was 'relatively more complex' than the identification and deployment tasks and operators tended to 'fixate' on this to the exclusion of the others, i.e. horizontal operators encountered time-sharing problems. This conclusion may be elaborated upon by suggesting that even at the high level of complexity, i.e. when a greater number of aircraft were involved, input complexity was not high enough to overload the first vertical operator. However, this same initial task (monitoring and tracking) was of sufficiently high complexity, e.g. a high degree of motor demands were imposed, and bore little intra-task organisation to the later identification and deployment tasks, that time-sharing problems for horizontal operators were inevitable. Such a conclusion is very similar to that drawn from the results of the first experiment in the present programme of research.

Other relevant research is that which has studied the effects of interaction, or inter-task organisation, at the input and output levels (see Chapter 2.3. page 52). A series of studies by Lanzetta and Roby (Roby and Lanzetta, 1956; Lanzetta and Roby, 1956 (a); Lanzetta and Roby, 1957) investigated the effects of interaction at the input level where operators organised horizontally must approach a number of other team members to acquire information needed for task completion. They found that, generally, the more operators were autonomous, i.e. all required information was directly available to them, the better the performance of the team. However, in the last of their experiments, they warn that too much autonomy may lead to overloading of certain positions in the team (Roby and Lanzetta, 1957). One can hypothesize that the onset of overload on a single operator may be prevented if the tasks allocated to each team member have a high degree of intra-task organisation, and impose similar levels of complexity on all team members. If tasks allocated to an operator are also relatively independent of those allocated to another, then the level of inter-task organisation can also be reduced. Alternatively, if a task was of high complexity and bore little intra-task organisation to other tasks, it may be preferable to have this task performed by a functionally-specialised operator connected vertically to the rest of the team. The interference effects of interaction have also been studied at the output level (e.g. the series of studies by Briggs et al. 1965-1968), where horizontal operators are required to co-ordinate their responses to produce a single output. Results from the fourth experiment tend to agree with the key finding in this area, that verbal communication when not actually required by the task, is interfering rather than beneficial to team performance.

Many computer-based command and control systems appear to contain most of the features where a horizontal organisation would be preferable to a vertical organisation. Such systems are usually typified by a high range and volume of inputs to the system and the availability of software and display capabilities which can reduce the complexity of individual tasks as well as increase the level of intra-task organisation between them. Performance could be further improved by the design of software to give greater autonomy for horizontal operators. For example, the computer could sort inputs to the system and present them to the appropriate operator, or responses could be summated to reduce interaction at the output level. The interaction requirements of the vertical organisation could also be decreased through possible improvements in the ease of information transmission, e.g. verbal communication between operators can be replaced by visual modes of communication via visual display units. However, unless some form of computer-assistance was available to reduce input complexity, the first operator in this type of organisation would still be susceptible to overload at high input levels.

Flexibility in manning may be required to cope with varying levels of task complexity. The horizontal organisation would appear to be more conducive to such flexibility. It would be necessary to decide on how much complexity can be handled capably, in terms of speed and accuracy criteria, by a single operator. The total task complexity may be divided equally amongst additional operators just as it was divided between two in the experimental work, e.g. the scenario may be split three, four, five or more ways depending on the number of operators. Similarly, if each operator were responsible for two tracks, then eight tracks would necessitate a four-man team. Conversely, at low levels of complexity, one-man operation may be possible. Operators, all adequately trained, can be added or subtracted as required in a horizontal organisation. However, in a vertical organisation, problems arise from trying to incorporate additional operators into a team whose structure necessitates co-ordination between operators.

Although a horizontal organisation has much to commend it, a team organised completely along horizontal lines may not always be the most desirable. In the experimental work carried out, this was possible because only three tasks were required and the individual complexity, dependency, and sequencing of these was such that the total task complexity could be divided between the two operators. However, if a greater number of tasks is required, their total complexity may be such that such an arrangement would create overload at individual operator positions. There was some evidence of this in the fifth experiment when the additional reporting task of a periodic status report led to a level of task complexity of too high a magnitude for effective time-sharing. The problem becomes one of how best to incorporate extra operators into the team to cope with this extra complexity. From experimental work carried out, the most optimum distribution of task demands would appear to depend on the characteristics of the tasks to be performed. Using the above guidelines all tasks with high intra-task organisation would, where possible, continue to be performed by an individual operator. A task with little intra-task organisation, and/or one with a high level of complexity could be allocated to a separate functionally-specialised operator. In the fifth experiment, for example, it would be logical to allocate the highly complex, low intra-task organisation, status reporting task to a third operator, leaving the two horizontal operators to devote their time to more organised tasks. A hybrid team organisation would result, incorporating elements of both vertical and horizontal organisation. Two operators working in horizontal organisation would be connected vertically to the third operator.

Indeed, it would appear that for a wide variety of tasks in the multiman-machine system, the most effective team would be one utilising both vertical and horizontal structures. However, to distribute tasks optimally among team members, consideration must first of all be given to the demands imposed by tasks, particularly those arising from the characteristics of tasks, such as their complexity and organisation. This study has attempted to provide guidelines to help systems designers approach the problem of reconciling those task demands with the most appropriate mode of team organisation.

APPENDIX I

INSTRUCTIONS/JOB AID

EXPERIMENTS 2, 3, 4 and 5

a) Vertical Condition - Operator 1

1. Through the DEC writer you will be presented with information relating to 4 tracks. This raw information needs to be processed in order to identify which of the four tracks each piece of information refers to, i.e. a label must be attached to each code number. (up to 8 tracks in Exps 3, 4 and 5).

   e.g. On DEC writer:

   CODE 71: 284 degrees, 2720 yards
   CODE 72: 123 degrees, 1070 yards

2. On your VDU, you will first be asked:

   "ACTION? (L, M or T)"

   (i) Press L if you wish to label.
   (ii) Press M if you would like a map or plot of what has occurred previously.
   (iii) Press T if you would like a table to show previous labels given.

3. "CODE NUMBER" - enter code number from DEC writer.

4. "WHICH LABEL DO YOU WANT TO GIVE?" - use letters A, B, C, D (plus letters E, F, G and H in Experiments 3, 4 and 5).

   Here, you may wish to see a table or map to help you. Press T or M as required.

N.B. After pressing keys, you must press the RETURN key to continue. If you should want to clear the screen, press Z.

INSTRUCTIONS/JOB AID

EXPERIMENTS 2, 3, 4 and 5

b) Vertical Condition - Operator 2

1. Through the DEC writer you will be presented with track information labelled appropriately by your accomplice, Operator 1. This information needs to be plotted so that it will be possible to find out any changes, i.e. speed or course changes, in any of the tracks. Changes must then be reported.

   e.g. on DEC writer:

   CODE 71 HAS BEEN LABELLED "A"
   CODE 72 HAS BEEN LABELLED "B"

2. On your VDU you will first be asked:

   "ACTION (P, M or T).

   (i) To plot press P
   (ii) To get the map (for reporting purposes) press M
   (iii) T will give you a table of previous labelling

3. "CODE NUMBER" - enter appropriate code number.

4. "PLOT THIS ENTRY?" - type Y to plot.

5. After each plot, look at your map to follow the progression of tracks.

   N.B. Changes will be either SPEED (the length of line will increase)
   or COURSE

   These must be reported.

6. To report press the intercom button (AND KEEP DEPRESSED) and speak after the following format:

   e.g. "CODE 10 TRACK B SPEED CHANGE"

   or "CODE 15 TRACK D COURSE CHANGE"

   etc.

After each key press, you must press the RETURN key to continue.
If you should want to clear the screen, press Z.

INSTRUCTIONS/JOB AID

EXPERIMENTS 2, 3, 4 and 5

c) Horizontal Condition - Operator 1
   Label, Plot and Report

1. Through the DEC writer, you will be presented with information relating to 4 tracks - YOU ARE RESPONSIBLE FOR 2 OF THESE - THOSE APPEARING BETWEEN 270° - 090°. (8 and 4 respectively in Expts 3, 4 and 5).

2. This raw information needs to be processed in order to identify which of the 4 tracks each piece of information refers to, i.e. a label must be attached to each code number.

   e.g. on DEC writer:

   CODE 23: 310 degrees, 2800 yards
   CODE 24: 123 degrees, 4000 yards

3. In the above example, you will only be required to process Code 23.

4. On your VDU, you will first be asked:

   "ACTION? (L, M or T)"

   (i) Press L if you wish to label
   (ii) Press M if you would like a map or plot of what has occurred previously
   (iii) Press T if you would like a table to show previous labels given

5. "CODE NUMBER" - enter code number from DEC writer.

6. "WHICH LABEL DO YOU WANT TO GIVE?" - use A or B (plus C and D for Experiments 3, 4 and 5). Here you may wish to see a table or map to help you. Press T or M as required.

7. "PLOT THIS ENTRY?" - press Y to plot.

8. After each plot, look at your map to follow the progression of target tracks.

   N.B. Changes will be either SPEED (the length of line will increase) or COURSE
   These must be reported.

9. To report, press the intercom button (and keep depressed) and speak after the following format.

   e.g. "CODE 23 TRACK A SPEED CHANGE"
   "CODE 28 TRACK B COURSE CHANGE"

   After each key press, you must press the RETURN key to continue. If you should want to clear the screen, press Z.

   N.B. Operator 2 performs exactly the same operations for contacts appearing between 091° and 269°, using track labels E and F (plus G and H for Experiments 3, 4 and 5).

APPENDIX II

EXPERIMENT 5

THE STATUS REPORT - Additional instructions to subjects

Periodically, the words 'STATUS REPORT DUE NOW' appear on the lineprinter. When this occurs, you must press the S key to status report as soon as possible.

On your VDU you will be asked:

(i) "HOW MANY TRACKS?" - enter the appropriate number.

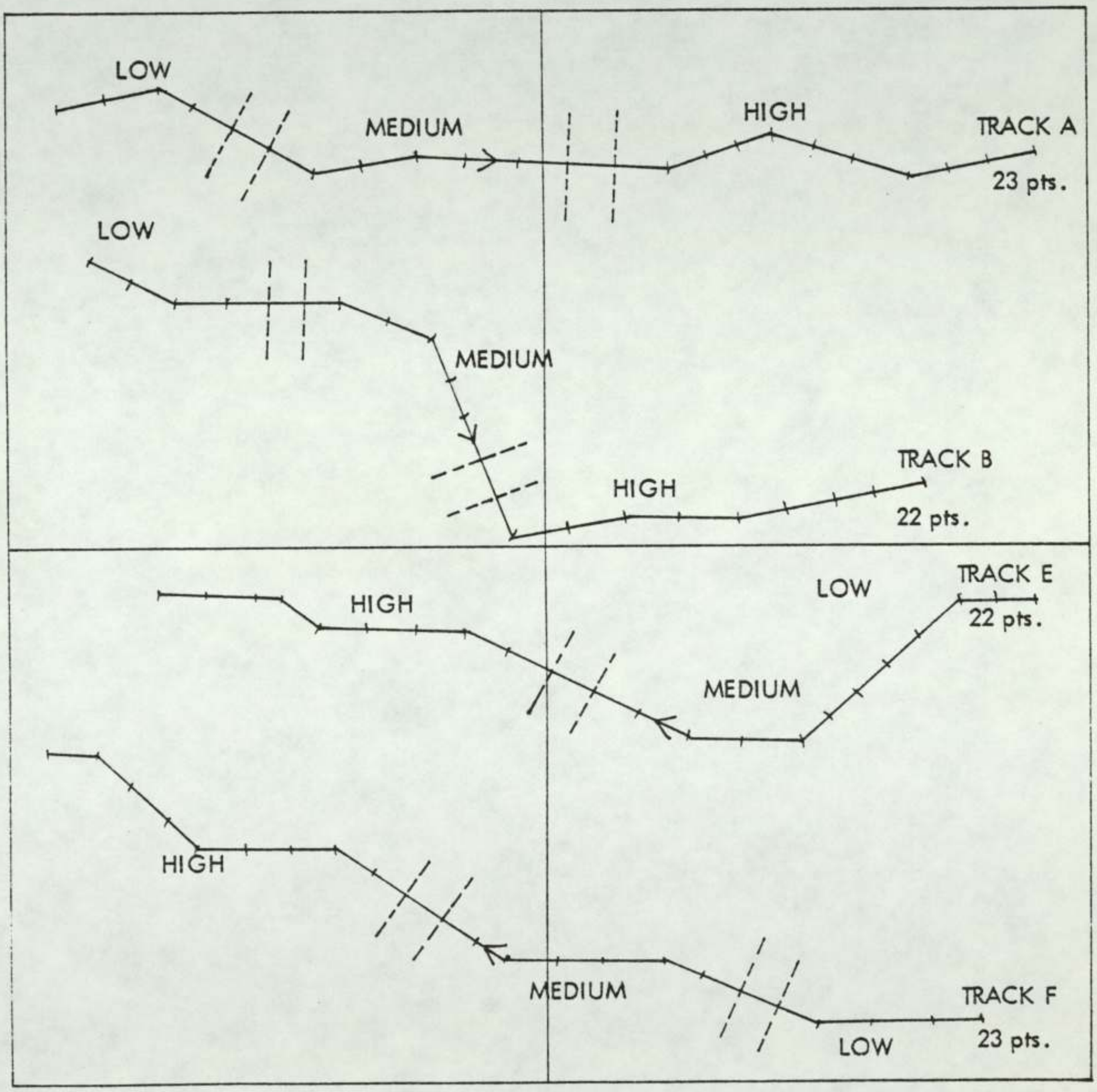
(ii) "HOW MANY CONVERGING?" - enter the appropriate number. Your map and/or table will help you decide which tracks are approaching. If only one contact per track, assume non-converging.

(iii) "HOW MANY BETWEEN 300 and 200 yards?")
(iv) "HOW MANY BETWEEN 200 and 100 yards?") your table will help you answer these questions.
(v) "HOW MANY BETWEEN 100 and 0 yards?")

The end of the status report is marked by an evaluation output on the lineprinter. You then continue plotting and verbal reporting as before until the next status report is due.

APPENDIX III

EXPERIMENT 2
TRACKS FORMAT - EXAMPLE TAKEN FROM LOW-MEDIUM HIGH PRESENTATION



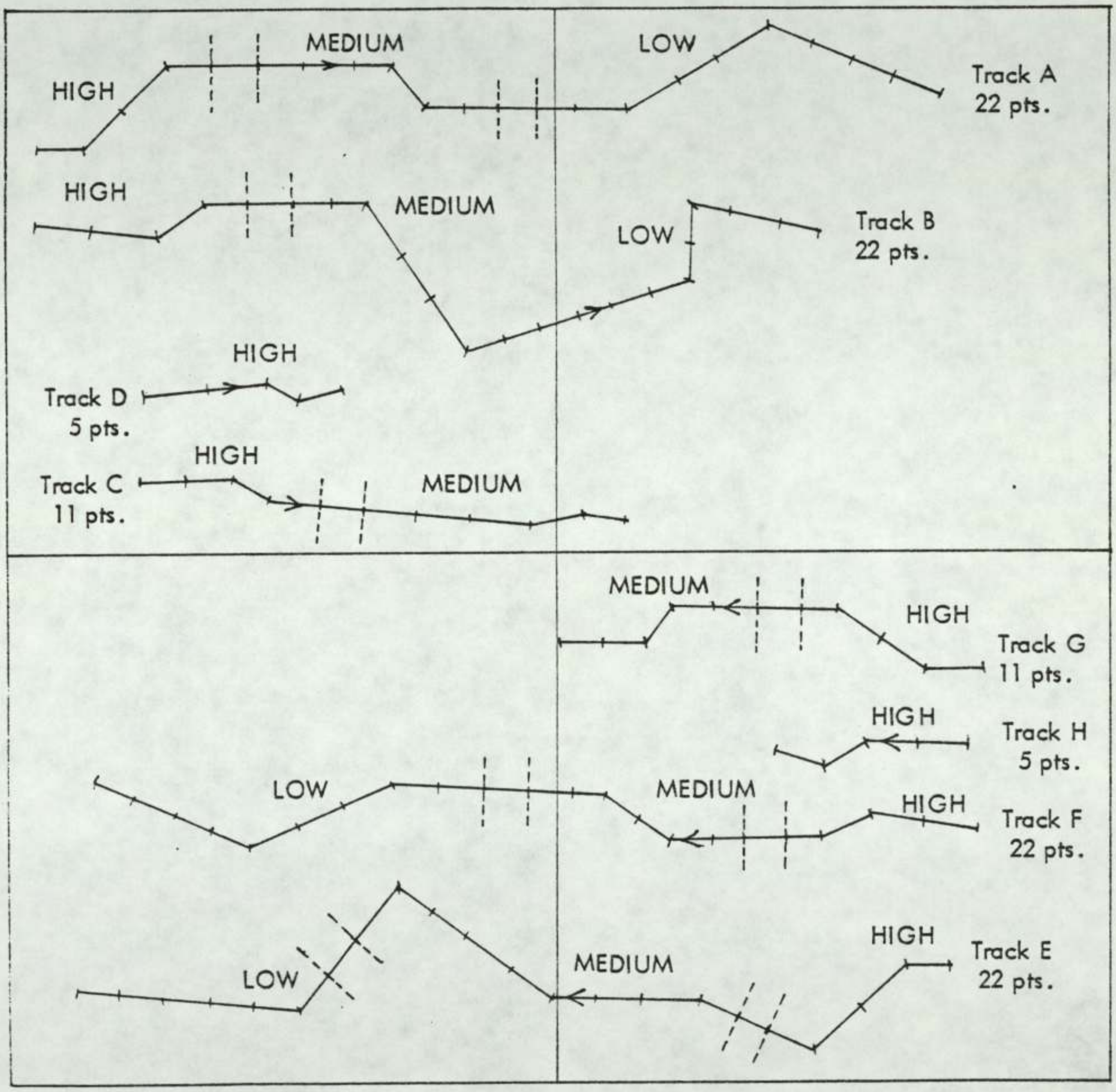
Speed changes shown by increase in distance between consecutive points.

N.B. The display appearing on the VDU is 5" square.

APPENDIX IV

EXPERIMENT 3

TRACKS FORMAT - EXAMPLE TAKEN FROM HIGH-MEDIUM-LOW PRESENTATION



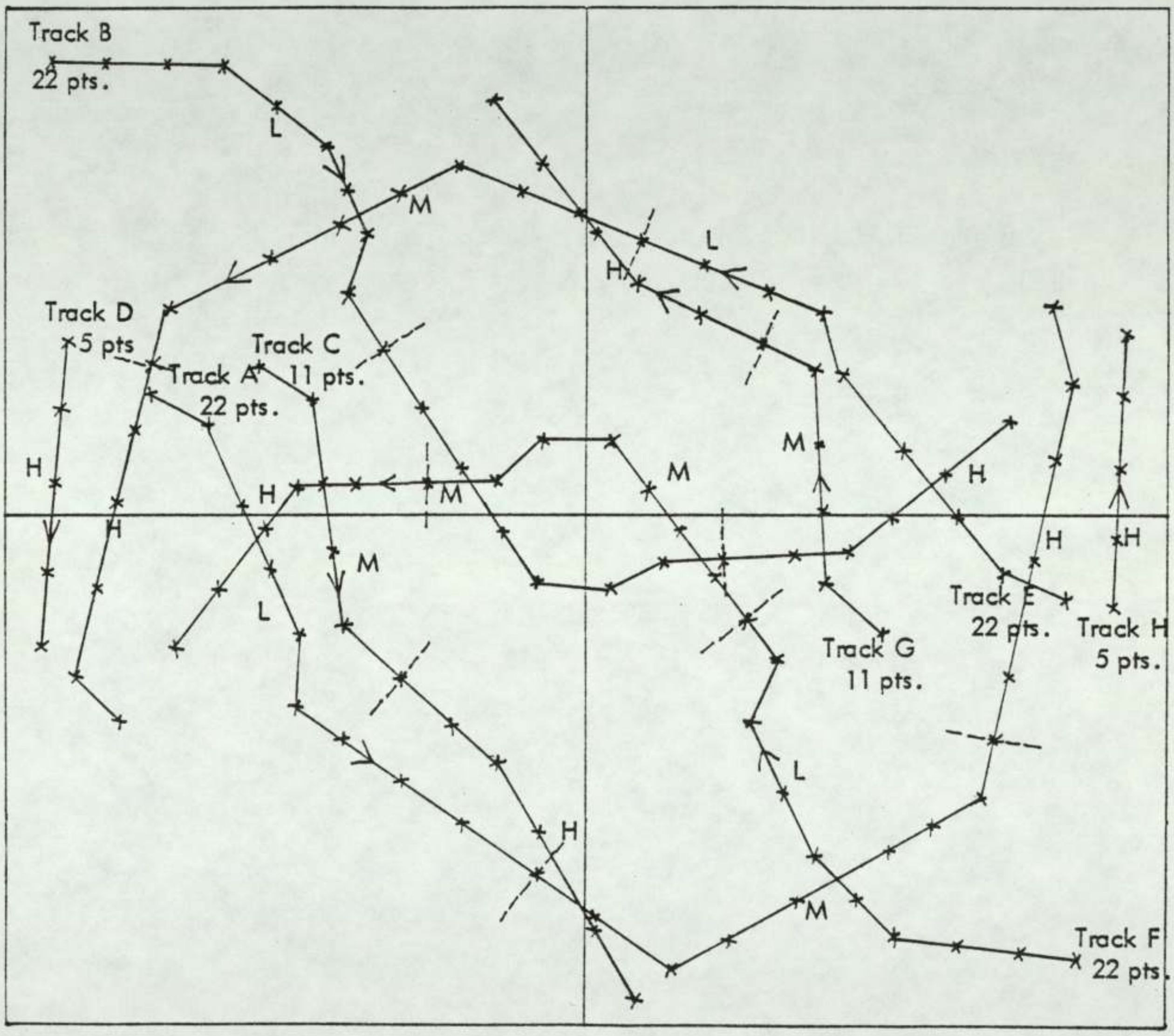
Speed changes shown by increase in distance between consecutive points.

N.B. The display appearing on the VDU is 5" square.

APPENDIX V

EXPERIMENT 4

TRACKS FORMAT - EXAMPLE TAKEN FROM LOW-MEDIUM-HIGH PRESENTATION



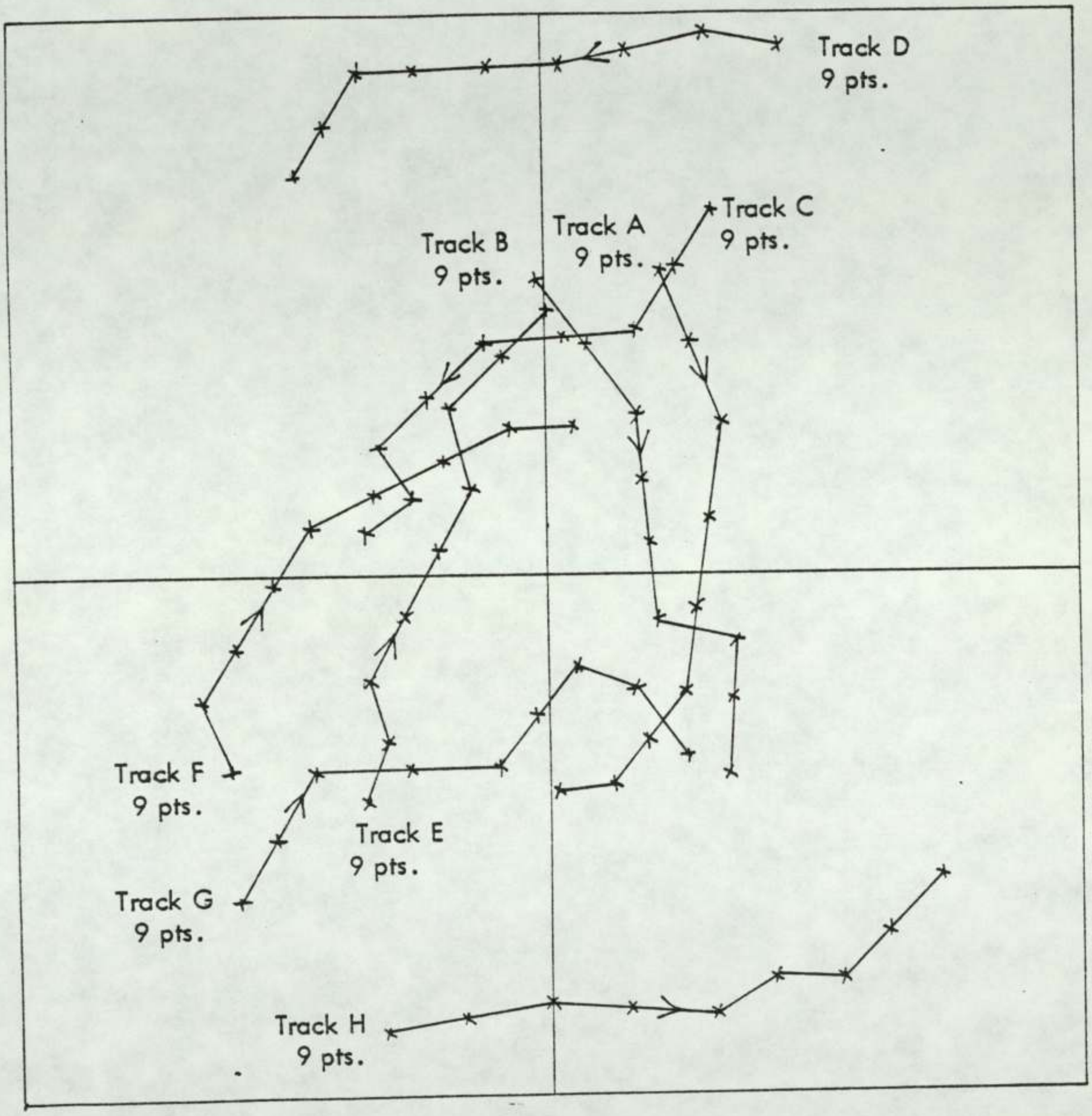
Speed changes by increase in distance between consecutive points.

N.B. The display appearing on the VDU is 5" square.

APPENDIX VI

EXPERIMENT 5

TRACKS FORMAT



Speed changes shown by increase in distance between consecutive points.

N.B. The display appearing on the VDU is 5" square.

APPENDIX VII

EXPERIMENT I

Sources of variance in team performance scores and their significance level

a) TBP Plotting Errors

Source of variance	S.S	df	M.S.	F	Sig. level
Organisation	16	1	16	2.67	N.S.
Complexity	2761	1	2761	460	<0.01
Comp. x Organisation	27	1	27	4.5	N.S.
Residual	48	8	6		
Total	2852	11			

b) Plotting errors by type - High load

Source of variance	S.S.	df	M.S.	F	Sig. level
Organisation	30.08	1	30.08	1.02	N.S.
Error Type	36.75	1	36.75	1.25	N.S.
Error Type x Organisation	874	1	874	29.82	<0.01
Residual	234.42	8	29.30		
Total	1175.25	11			

c) Simple Main effects - Error Type and Organisation

Source of variance	S.S.	df	M.S.	F	Sig. level
Organisation x Commission	267	1	267	9.11	<0.05
Organisation x Omission	600	1	600	20.47	<0.01
w. cell	234.42	8	29.3		

NB In the tables 'organisation' refers to team organisation.

APPENDIX VIII

EXPERIMENT 2

Sources of variance in team performance scores and their significance level

a) Time measures

i) Av. time to plot

Source	ss	df	ms	F	Sig. level
Between subjects	31028.33	11			
Organisation	27777.78	1	27777.78	85.45	<0.01
Error	3250.55	10	325.05		
Within subjects	21460.67	19			
Complexity	9716.16	2	4858.08	14.38	<0.01
Comp. x Organisation	4990.39	2	2495.19	7.39	<0.01
Error	6754.11	20	337.7		

Simple main effects - Av. time to plot

Source	ss	df	ms	F	Sig. level
Organisation x Low comp.	3234.08	1	3234.08	14.36	<0.01
Organisation x Medium comp.	6302.08	1	6302.08	27.99	<0.01
Organisation x High comp.	23232	1	23232	103.19	<0.01
Error	6754.11	30	225.13		

ii) Av. wait time

Source	ss	df	ms	F	Sig. level
Between subjects	15400.25	11			
Organisation	10643.36	1	10643.36	22.37	<0.01
Error	4756.89	10	475.69		
Within subjects	14767	19			
Complexity	6220.17	2	3110.08	10.37	<0.01
Comp. x Organisation	2547.72	2	1273.87	4.25	<0.05
Error	5999.11	20	299.95		

NB In the tables 'organisation' refers to team organisation.

Simple main effects - Av. wait time

Source	ss	df	ms	F	Sig. level
Organisation x Low comp.	833.33	1	833.33	4.16	N.S.
Organisation x Medium comp.	2610.75	1	2610.75	13.06	<0.01
Organisation x High comp.	9747	1	9747	48.74	<0.01
Error	5999.11	30	199.97		

iii) Av. process time

Source	ss	df	ms	F	Sig. level
Between subjects	3501.25	11			
Organisation	3422.25	1	3422.25	433.19	<0.01
Error	79	10	7.9		
Within subjects	917.50	19			
Complexity	171.50	2	85.75	3.09	N.S.
Complexity x Organisation	190.16	2	95.08	3.42	N.S.
Error	555.83	20			

iv) Av. label time

Source	ss	df	ms	F	Sig. level
Between subjects	391.42	11			
Organisation	283.36	1	283.36	26.21	<0.01
Error	108.06	10	10.81		
Within subjects	104.83	19			
Complexity	0	2	0	0	N.S.
Complexity x Organisation	0.22	2	0.11	0.02	N.S.
Error	104.61	20	5.23		

v) Av. communication time

Source	ss	df	ms	F	Sig. level
Between subjects	1964.47	11			
Organisation	1750.02	1	1750.02	81.60	<0.01
Error	214.45	10	21.44		
Within subjects	720.33	19			
Complexity	168.73	2	84.36	4.47	<0.05
Complexity x Organisation	174.39	2	87.19	4.62	<0.05
Error	377.22	20	18.86		

Simple main effects - Av. communication time

Source	ss	df	ms	F	Sig. level
Organisation x Low comp.	341.33	1	341.33	27.15	<0.01
Organisation x Medium comp.	363	1	363	28.87	<0.01
Organisation x High comp.	1220.09	1	1220.09	97.06	<0.01
Error	377.22	30	12.57		

vi) Av. plot - report time

Source	ss	df	ms	F	Sig. level
Between subjects	1397.74	11			
Organisation	697.84	1	697.84	9.97	<0.05
Error	699.90	10	69.99		
Within subjects	54.83	19			
Complexity	3.01	2	1.51	0.61	N.S.
Complexity x Organisation	2.10	2	1.05	0.42	N.S.
Error	49.72	20	2.49		

b) Accuracy measures

i) No. contacts plotted

Source	ss	df	ms	F	Sig. level
Between subjects	943.10	11			
Organisation	818.91	1	818.91	65.94	<0.01
Error	124.18	10	12.41		
Within subjects	2532.25	19			
Complexity	1154.23	2	577.11	20.39	<0.01
Complexity x Organisation	812.08	2	406.04	14.34	<0.01
Error	564.95	20	28.26		

Simple main effects - No. contacts plotted

Source	ss	df	ms	F	Sig. level
Organisation at					
Low comp.	0	1	0	0	N.S.
Medium comp.	112	1	112	5.94	<0.05
High comp.	1518.75	1	1518.75	80.53	<0.01
Error	564.95	30	18.86		

ii) No. wrong labels

Source	ss	df	ms	F	Sig. level
Between subjects	479.64	11			
Organisation	42.25	1	42.25	0.97	N.S.
Error	437.39	10	43.74		
Within subjects	772.67	19			
Complexity	184.89	2	92.44	3.15	N.S.
Complexity x Organisation	2.00	2	1.00	0.03	N.S.
Error	585.78	20	29.78		

iii) No. correct reports

Source	ss	df	ms	F	Sig. level
Between subjects	2268.54	11			
Organisation	0.48	1	0.48	0.002	N.S.
Error	2268.05	10	226.80		
Within subjects	9312.88	19			
Complexity	4437.47	2	2218.74	10.77	<0.01
Complexity x Organisation	756.09	2	378.04	1.83	N.S.
Error	4119.32	20	205.97		

iv) No. reporting errors

Source	ss	df	ms	F	Sig. level
Between subjects	140.97	11			
Organisation	0.03	1	0.03	0.002	N.S.
Error	140.94	20	7.41		
Within subjects	638.67	19			
Complexity	480.05	2	240.03	31.13	<0.01
Complexity x Organisation	4.39	2	2.19	0.28	N.S.
Error	154.22	20	7.71		

v) Type of error: a) Missed changes

Source	ss	df	ms	F	Sig. level
Between subjects					
Organisation	12.25	1	12.25	3.22	N.S.
Within subjects					
Complexity	281.56	2	140.78	37.05	<0.01
Comp. x Organisation	62.5	2	31.25	8.22	<0.01
Residual	114	30	3.8		
Total	494.31				

Simple main effects - Missed changes

Source	ss	df	ms	F	Sig. level
Organisation x low comp.	0.08	1	0.08	0.02	N.S.
Organisation x medium comp.	4.08	1	4.08	1.07	N.S.
Organisation x high comp.	70.08	1	70.08	18.44	<0.01
Error	114	30	3.8		

i) Type of error: b) Inaccurate reports and false alarms

Source	ss	df	ms	F	Sig. level
Between subjects					
Organisation	20.02	1	20.02	3.11	N.S.
Within subjects					
Complexity	29.58	2	14.79	2.3	N.S.
Complexity x Organisation	28.64	2	14.32	2.22	N.S.
Residual	192.76	30	6.43		
Total	271				

APPENDIX IX

EXPERIMENT 3

Sources of variance in team performance scores and their significance level

a) Time measures

i) Av. time to plot

Source	ss	df	ms	F	Sig. level
Between subjects	22178.75	11			
Organisation	13963.36	1	13963.36	16.99	<0.01
Error	8215.39	10	821.54		
Within subjects	16978	19			
Complexity	8750	2	4375	18.03	<0.01
comp. x Organisation	3376.22	2	1688.11	6.96	<0.01
Error	4851.77	20	242.59		

NB In the tables 'organisation' refers to team organisation.

Simple main effects - Av. time to plot

Source	ss	df	ms	F	Sig. level
Organisation x low comp.	3366.75	1	3366.75	20.82	<0.01
Organisation x medium comp.	1102.09	1	1102.09	6.81	<0.05
Organisation x high comp.	12870.75	1	12870.75	79.58	<0.01
Error	4851.77	30	161.73		

ii) Av. wait time

Source	ss	df	ms	F	Sig. level
Between subjects	7701.74	11			
Organisation	3373.67	1	3373.67	7.79	<0.05
Error	4328.07	10	432.80		
Within subjects	16223.83	19			
Complexity	8192.89	2	4096.44	18.44	<0.01
Comp. x Organisation	3587.56	2	1793.78	8.07	<0.01
Error	4443.39	20	222.17		

Simple main effects - Av. wait time

Source	ss	df	ms	F	Sig. level
Organisation x low comp.	357.52	1	357.52	2.41	N.S.
Organisation x medium comp.	0.19	1	0.19	-	N.S.
Organisation x high comp.	6603.52	1	6603.52	44.59	<0.01
Error	4443.39	30	148.11		

iii) Av. process time

Source	ss	df	ms	F	Sig. level
Between subjects	5235.19	11			
Organisation	3412.51	1	3412.51	18.72	<0.01
Error	1822.68	10	182.27		
Within subjects	846.5	19			
Complexity	0.67	2	0.33	0.0084	N.S.
Comp. x Organisation	49.56	2	24.78	0.6223	N.S.
Error	796.28	20	39.81		

iv) Av. label time

Source	ss	df	ms	F	Sig. level
Between subjects	126.41	11			
Organisation	3.06	1	3.06	0.24	N.S.
Error	123.35	10	12.33		
Within subjects	234.67	19			
Complexity	49.68	2	24.84	2.73	N.S.
Comp. x Organisation	3.12	2	1.56	0.17	N.S.
Error	181.86	20	9.09		

v) Av. communication time

Source	ss	df	ms	F	Sig. level
Between subjects	4602.97	11			
Organisation	3025	1	3025	19.17	<0.01
Error	1577.97	10	157.78		
Within subjects	926	19			
Complexity	19.68	2	9.84	0.22	N.S.
Comp. x Organisation	42.12	2	21.06	0.49	N.S.
Error	864.19	20	43.21		

vi) Av. plot report time

Source	ss	df	ms	F	Sig. level
Between subjects	185.57	11			
Organisation	122.84	1	122.84	19.58	<0.01
Error	62.73	10	6.27		
Within subjects	149.83	19			
Complexity	35.09	2	17.54	4.64	<0.05
Comp x Organisation	39.18	2	19.59	5.18	<0.05
Error	75.55	20	3.77		

Simple main effects - Av. plot report time

Source	ss	df	ms	F	Sig. level
Organisation x low comp.	6.75	1	6.75	2.68	N.S.
Organisation x medium comp.	28.52	1	28.52	11.32	<0.01
Organisation x high comp.	126.75	1	126.75	50.29	<0.01
Error	75.55	30	2.52		

b) Accuracy measures

i) No. contacts plotted

Source	ss	df	ms	F	Sig. level
Between subjects	700.52	11			
Organisation	166.84	1	166.84	3.12	N.S.
Error	533.68	10	53.36		
Within subjects	829.17	19			
Complexity	357.29	2	178.64	10.43	<0.01
Comp.x Organisation	129.51	2	64.75	3.79	<0.05
Error	342.36	20	17.11		

Simple main effects - No. contacts plotted

Source	ss	df	ms	F	Sig. level
Organisation x low comp.	2.08	1	2.08	0.18	N.S.
Organisation x medium comp.	18.75	1	18.75	1.64	N.S.
Organisation x high comp.	274.52	1	274.52	24.06	<0.01
Error	342.36	30	11.41		

ii) No. wrong labels

Source	ss	df	ms	F	Sig. level
Between subjects	970.30	11			
Organisation	173.36	1	173.36	2.17	N.S.
Error	796.94	10	79.69		
Within subjects	684.67	19			
Complexity	130.05	2	65.02	2.38	N.S.
Comp. x Organisation	7.39	2	3.69	0.13	N.S.
Error	547.22	20	27.36		

iii) No. correct reports

Source	ss	df	ms	F	Sig. level
Between subjects	1366.16	11			
Organisation	0.01	1	0.01	0.0001	N.S.
Error	1366.14	10	136.61		
Within subjects	4107.52	19			
Complexity	2115.02	2	1057.51	11.84	<0.01
Comp. x Organisation	206.41	2	103.21	1.15	N.S.
Error	1786.09	20	89.30		

iv) No. reporting errors

Source	ss	df	ms	F	Sig. level
Between subjects	95.33	11			
Organisation	0.44	1	0.44	0.04	N.S.
Error	94.89	20	9.49		
Within subjects	196.67	19			
Complexity	102.16	2	51.08	12.00	<0.01
Comp.x Organisation	9.39	2	4.69	1.10	N.S.
Error	85.11	20	4.25		

v) Type of error: a) Missed changes

Source	ss	df	ms	F	Sig. level
Between subjects					
Organisation	1.89	1	1.89	0.45	N.S.
Within subjects					
Complexity	127.16	2	63.58	15.21	<0.01
Comp.x Organisation	2.62	2	1.31	0.31	N.S.
Residual	125.33	30	4.18		
Total	257				

vi) Type of error: b) Inaccurate and false alarms

Source	ss	df	ms	F	Sig. level
Between subjects					
Organisation	0.69	1	0.69	0.5	N.S.
Within subjects					
Complexity	2	2	1	0.72	N.S.
Comp.x Organisation	2.69	2	1.35	0.98	N.S.
Residual	41.37	30	1.38		
Total	46.75				

APPENDIX X

EXPERIMENT 4

Sources of variance in team performance scores and their significance level.

a) Time measures

i) Av. time plot

Source	ss	df	ms	F	Sig.level
Between subjects	56146.33	15			
Organisation	20321.5	3	6773.83	2.26	NS
Error	35824.33	12	2985.4		
Within subjects	23529.33	21			
Complexity	11305.79	2	5652.89	14.99	<0.01
Comp. x Organisation	3172.87	6	528.81	1.40	NS
Error	9050.66	24	377.11		

ii) Av. wait time

Source	ss	df	ms	F	Sig.level
Between subjects	43555.87	15			
Organisation	8371.64	3	2790.55	0.95	NS
Error	35184.23	12	2932.02		
Within subjects	18486.83	21			
Complexity	7029.03	2	3514.52	9.89	<0.01
Comp.x Organisation	2927.97	6	487.99	1.37	NS
Error	8529.83	24	355.41		

iii) Av. process time

Source	ss	df	ms	F	Sig.level
Between subjects	8130.70	15			
Organisation	7452.56	3	2484.19	43.96	<0.01
Error	678.15	12	56.51		
Within subjects	3276.5	21			
Complexity	456.22	2	228.11	2.22	NS
Comp. x Organisation	351.11	6	58.52	0.57	NS
Error	2469.17	24	102.88		

NB In the tables 'organisation' refers to team organisation.

Tukey Multiple Comparison of Means - Av. process time

Means: 50.83 Vertical
23 H.ind.
20.75 H.co-op.
20.33 H.part

	n=k=4		k=3		k=2	
	<0.05	<0.01	<0.05	<0.01	<0.05	<0.01
SR(n)	3.9	4.91	3.9	4.91	3.9	4.91
SR(k)	3.9	4.91	3.53	4.54	2.92	3.96
Av.SR	3.9	4.91	3.71	4.72	3.41	4.43
S	2.93	2.93	2.93	2.93	2.93	2.93
WSD	11.43	14.39	10.87	13.83	9.99	12.99

iv) Av. label time

Source	ss	df	ms	F	Sig.level
Between subjects	544	15			
Organisation	110.5	3	36.83	1.02	NS
Error	433.5	12	36.12		
Within subjects	1244.67	21			
Complexity	780.29	2	390.15	28.29	<0.01
Comp. x Organisation	133.38	6	22.23	1.61	NS
Error	331	24	13.79		

v) Av. communication time

Source	ss	df	ms	F	Sig.level
Between subjects	8825.91	15			
Organisation	8265.43	3	2755.14	59.99	<0.01
Error	560.48	12	46.71		
Within subjects	2113.17	21			
Complexity	31.53	2	15.77	0.18	NS
Comp. x Organisation	17.30	6	2.88	0.03	NS
Error	2064.33	24	86.01		

Tukey Multiple Comparison of Means - Av. communication time

Means: 33.37 Vertical
3.66 H.ind.
2.99 H.co-op
2.58 H.part

	n=4	k=2
	<0.05	<0.01
SR(n)	3.9	4.91
SR(k)	2.92	3.96
Av.SR	3.41	4.43
S	2.68	2.68
WSD	9.13	11.87

vi) Av. plot report time

Source	ss	df	ms	F	Sig.level
Between subjects	79.96	15			
Organisation	54.69	3	18.23	8.66	<0.01
Error	25.27	12	2.11		
Within subjects	196.42	21			
Complexity	117.31	2	58.66	46.49	<0.01
Comp. x Organisation	48.76	6	8.13	6.42	<0.01
Error	30.34	24	1.26		

Simple Main Effects - Av. plot-report time

Source	ss	df	ms	F	Sig.level
Org.x low comp.	2.08	3	0.69	<1	NS
Org.x medium comp	20.74	3	6.91	8.23	<0.01
Org.x high comp.	80.69	3	26.90	32.02	<0.01
Error	30.34	36	0.84		

b) Accuracy measures

i) No.contacts plotted

Source	ss	df	ms	F	Sig.level
Between subjects	464.81	15			
Organisation	74.23	3	24.74	0.76	NS
Error	390.58	12	32.55		
Within subjects	534.67	21			
Complexity	338.04	2	169.02	29.04	<0.01
Comp. x Organisation	56.96	6	9.49	1.63	NS
Error	139.66	24	5.82		

ii) No. wrong labels

Source	ss	df	ms	F	Sig.level
Between subjects	2360.31	15			
Organisation	1704.73	3	568.24	10.40	<0.01
Error	655.58	12	54.63		
Within subjects	4962	21			
Complexity	2214.5	2	1107.25	15.05	<0.01
Comp. x Organisation	982.33	6	163.72	2.23	NS
Error	1765.17	24	73.55		

Tukey Multiple Comparison of Means - No. wrong labels

Means: 25.83 H.part.
16.66 H.ind.
12.5 Vertical
10.25 H.co-op

	n=k=4		k=3		k=2	
	<0.05	<0.01	<0.05	<0.01	<0.05	<0.01
SR(n)	3.9	4.91	3.9	4.91	3.9	4.91
SR(k)	3.9	4.91	3.53	4.54	2.92	3.96
AvSR	3.9	4.91	3.71	4.72	3.41	4.43
S	2.48	2.48	2.48	2.48	2.48	2.48
WSD	9.67	12.18	9.2	11.7	8.46	10.99

iii) No. correct reports

Source	ss	df	ms	F	Sig.level
Between subjects	150.65	15			
Organisation	28.73	3	9.58	0.94	NS
Error	121.92	12	10.16		
Within subjects	657.33	21			
Complexity	528.29	2	264.14	65.47	<0.01
Comp. x Organisation	32.21	6	5.73	1.33	NS
Error	96.83	24	4.03		

iv) <u>No. report errors</u>

Source	ss	df	ms	F	Sig.level
Between subjects	156.64	15			
Organisation	34.23	3	11.41	1.12	NS
Error	122.41	12	10.20		
Within subjects	667.33	21			
Complexity	529.17	2	264.58	58.61	<0.01
Comp. x Organisation	29.83	6	4.97	1.1	NS
Error	108.33	24	4.51		

c) <u>Verbal communication measures</u> (<u>Horizontal part and Horizontal co-op only</u>)

i) <u>Direct questions</u>

Source	ss	df	ms	F	Sig.level
Between subjects	129.29	7			
Organisation	51.04	1	51.04	3.91	NS
Error	78.25	6	13.04		
Within subjects	58.67	11			
Complexity	6.58	2	3.29	0.84	NS
Comp. x Organisation	5.58	2	2.79	0.72	NS
Error	46.5	12	3.87		

ii) <u>Direct responses</u>

Source	ss	df	ms	F	Sig.level
Between subjects	85.17	7			
Organisation	37.5	1	37.5	4.72	NS
Error	47.67	6	7.94		
Within subjects	45.33	11			
Complexity	3.25	2	1.62	0.52	NS
Comp. x Organisation	4.75	2	2.37	0.76	NS
Error	37.33	12	3.11		

iii) Voluntary assistance

Source	ss	df	ms	F	Sig.level
Between subjects	164.67	7			
Organisation	16.67	1	16.67	0.68	NS
Error	148	6	24.67		
Within subjects	68.67	11			
Complexity	4.33	2	2.17	0.47	NS
Comp.x Organisation	9.33	2	4.67	1.02	NS
Error	55	12	4.58		

APPENDIX XI

EXPERIMENT 4(a)

Sources of variance in team performance scores and their significance level

a) Time measures

i) Av. time plot

Source	ss	df	ms	F	Sig. level
Between subjects	47685.81	5			
Organisation	12450.84	1	12450.84	1.41	NS
Error	35234.97	4	8808.74		
Within subjects	17347.37	19			
Session	5814.06	1	5814.06	5.51	NS
Org. x session	495.06	1	495.06	0.47	NS
Error	4217.42	4	1054.35		
Comp.	3292.04	2	1646.02	21.20	<0.01
Comp. x org.	583.93	2	291.96	3.76	NS
Error	621.28	8	77.66		
Session x comp.	334.54	2	167.27	0.96	NS
Org. x comp. x session	594.54	2	297.27	1.70	NS
Error	1394.5	8	174.31		

ii) Av. wait time

Source	ss	df	ms	F	Sig. level
Between subjects	31072.80	5			
Organisation	1806.25	1	1806.25	0.25	NS
Error	29266.55	4	7316.64		
Within subjects	15977.50	19			
Session	2224.70	1	2224.70	2.03	NS
Org. x session	1778.03	1	1778.03	1.62	NS
Error	4376.78	4	1094.20		
Comp.	3202.05	2	1601.03	7.14	<0.05
Comp. x org.	201.50	2	100.75	0.45	NS
Error	1793.69	8	224.21		
Session x comp.	262.39	2	131.19	0.81	NS
org. x comp. x session	850.72	2	425.36	2.64	NS
Error	1287.64	8	160.95		

NB In the tables 'organisation' refers to team organisation.

iii) Av. process time

Source	ss	df	ms	F	Sig.level
Between subjects	5579.79	5			
Organisation	4911.67	1	4911.67	29.41	<0.01
Error	668.11	4	167.03		
Within subjects	4941.12	19			
Session	987	1	987	69.8	<0.01
Session x org.	495.06	1	495.06	35.01	<0.01
Error	56.56	4	14.14		
Comp.	9.85	2	4.92	0.02	NS
Comp. x org.	466.1	2	233.05	0.82	NS
Error	2272.8	8	284.10		
Session x comp.	142.34	2	71.17	1.43	NS
Org. x comp. session	112.54	2	56.27	1.13	NS
Error	398.86	8	49.86		

Simple main effects - Av. process time

Source	ss	df	ms	F	Sig.level
Org. x session 1	1421.12	1	1421.12	201	<0.01
Org. x session 2	381.6	1	381.6	53.97	<0.01
Error	56.56	8	7.07		

iv) Av. label time

Source	ss	df	ms	F	Sig.level
Between subjects	467.22	5			
Organisation	16	1	16	0.14	NS
Error	451.22	4	112.80		
Within subjects	555.5	19			
Session	75.11	1	75.11	31.81	<0.01
Org. x session	0.44	1	0.44	0.19	NS
Error	9.44	4	2.36		
Comp.	199.59	2	99.79	13.06	<0.01
Comp. x org.	147.54	2	73.77	9.66	<0.01
Error	61.11	8	7.63		
Session x comp.	10.93	2	5.46	1.21	NS
Org. x comp. session	10.09	2	5.04	1.11	NS
Error	36.22	8	4.53		

Simple Main Effects - Av. label time

Source	ss	df	ms	F	Sig.level
Org. x low comp.	21.17	1	21.17	1.72	NS
Org. x medium comp.	2.75	1	2.75	<1	NS
Org. x high comp.	58.6	1	58.6	4.77	<0.05
Error	147.54	12	12.29		

v) Av. communication time

Source	ss	df	ms	F	Sig.level
Between subjects	5565.73	5			
Organisation	4841.84	1	4841.84	26.75	<0.01
Error	723.89	4	180.97		
Within subjects	3845.46	19			
Session	423.67	1	423.67	21.51	<0.01
Org. x session	339.17	1	339.17	17.22	<0.05
Error	78.78	4	19.69		
Comp.	120.79	2	60.39	0.21	NS
Comp. x org.	99.18	2	49.59	0.17	NS
Error	2274.86	8	284.36		
Session x comp.	58.85	2	29.42	0.59	NS
Org. x comp. x session	53.18	2	26.59	0.53	NS
Error	396.97	8	49.62		

Simple Main Effects - Av. communication time

Source	ss	df	ms	F	Sig.level
Org. x session 1	1295.44	1	1295.44	131.65	<0.01
Org. x session 2	437.93	1	437.93	44.51	<0.01
Error	78.78	8	9.84		

vi) Av. plot-report time

Source	ss	df	ms	F	Sig.level
Between subjects	119.65	5			
Organisation	100.83	1	100.83	21.43	<0.01
Error	18.82	4	4.7		
Within subjects	125.15	19			
Session	4.52	1	4.52	19.41	<0.05
Org. x session	0.92	1	0.92	3.94	NS
Error	0.93	4	0.23		
Comp.	47.59	2	23.79	20.79	<0.01
Comp. x org.	43.28	2	21.64	18.9	<0.01
Error	9.15	8	1.14		
Session x comp.	6.67	2	3.33	2.87	NS
Org. x comp. x session	2.8	2	1.4	1.2	NS
Error	9.28	8	1.16		

Simple Main Effects - Av. plot-report time

Source	ss	df	ms	F	Sig.level
Org. x low comp.	0.47	1	0.47	<1	NS
Org. x medium comp.	5.53	1	5.53	5.53	<0.05
Org. x high comp.	49.7	1	49.7	49.7	<0.01
Error	9.15	12	0.76		

b) Accuracy measures

i) No. contacts plotted

Source	ss	df	ms	F	Sig.level
Between subjects	486.55	5			
Organisation	32.11	1	32.11	0.28	NS
Error	454.44	4	113.61		
Within subjects	304	19			
Session	36	1	36	3.92	NS
Org. x session	0	1	0	0	NS
Error	36.66	4	9.16		
Comp.	118.72	2	59.36	11.24	<0.01
Comp. x org.	7.05	2	3.52	0.67	NS
Error	42.22	8	5.28		
Session x comp.	22.17	2	11.08	2.33	NS
Org. x comp. x session	3.17	2	1.58	0.33	NS
Error	38	8	4.75		

ii) No. wrong labels

Source	ss	df	ms	F	Sig.level
Between subjects	924.66	5			
Organisation	58.77	1	58.77	0.27	NS
Error	865.88	4	216.47		
Within subjects	2193.33	19			
Session	40.11	1	40.11	1.9	NS
Org. x session	87.11	1	87.11	4.14	NS
Error	84.11	4	21.03		
Comp.	660.66	2	330.33	3.8	NS
Comp. x org.	429.55	2	214.77	2.48	NS
Error	694.11	8	86.76		
Session x comp.	21.55	2	10.77	0.58	NS
Org. x comp. x session	29.55	2	14.77	0.8	NS
Error	146.55	8	18.32		

iii) No. correct reports

Source	ss	df	ms	F	Sig.level
Between subjects	131.47	5			
Organisation	1.36	1	1.36	0.04	NS
Error	130.11	4	32.53		
Within subjects	384.17	19			
Session	30.25	1	30.25	3.79	NS
Org. x session	0.03	1	0.03	<1	NS
Error	31.89	4	7.97		
Comp.	222.39	2	111.19	20.74	<0.01
Comp. x org.	7.39	2	3.69	0.69	NS
Error	42.88	8	5.36		
Session x comp.	9.5	2	4.75	1.02	NS
Org. x comp. x session	2.72	2	1.36	0.29	NS
Error	37.11	8	4.63		

iv) No. report errors

Source	ss	df	ms	F	Sig.level
Between subjects	161.8	5			
Organisation	1.36	1	1.36	0.03	NS
Error	160.44	4	40.11		
Within subjects	418.5	19			
Session	30.25	1	30.25	3.75	NS
Org. x session	0.03	1	0.03	1	NS
Error	32.22	4	8.05		
Comp.	238.39	2	119.19	19.5	<0.01
Comp.x org.	13.72	2	6.86	1.12	NS
Error	48.89	8	6.11		
Session x comp.	4.17	2	2.08	0.38	NS
Org. x comp.x session	7.72	2	3.86	0.71	NS
Error	43.11	8	5.38		

APPENDIX XII

EXPERIMENT 5

Sources of variance in team performance scores and their significance level

a) Time measures

i) Av. time to plot

Source	ss	df	ms	F	Sig.level
Between subjects	94581.46	11			
Organisation	55539.08	2	27769.54	6.4	<0.05
Error	39042.37	9	4338.04		
Within subjects	54451.5	7			
Session	50876.04	1	50876.04	164.77	<0.01
Session x org	796.58	2	398.29	1.29	NS
Error	2778.87	9	308.76		

Tukey Multiple Comparison of Means - Av. time to plot

Means: 251.62 Vertical
157 H.co-op
143.5 H.ind

	n=k=3		k=2	
	<0.05	<0.01	<0.05	<0.01
SR(n)	3.95	5.43	3.95	5.43
SR(k)	3.95	5.43	3.20	4.60
Av SR	3.95	5.43	3.57	5.01
S	6.21	6.21	6.21	6.21
WSD	24.53	33.72	22.17	31.14

ii) Av. wait time

Source	ss	df	ms	F	Sig.level
Between subjects	50588.33	11			
Organisation	13200.33	2	6600.16	1.59	NS
Error	37388	9	4154.22		
Within subjects	29938	7			
Session	23437.5	1	23437.5	40.74	<0.01
Session x org	1324	2	662	1.15	NS
Error	5177.5	9	575.28		

NB In the tables 'organisation' refers to team organisation.

iii) Av. process time

Source	ss	df	ms	F	Sig.level
Between subjects	141584.46	11			
Organisation	132094.08	2	66047.04	62.63	<0.01
Error	9490.37	9	1054.49		
Within subjects	7165.5	7			
Session	2709.37	1	2709.37	20.72	<0.01
Session x org	3279.25	2	1639.62	12.54	<0.01
Error	1176.87	9	130.76		

Simple Main Effects - Av. process time

Source	ss	df	ms	F	Sig.level
Org x session 1	88467.17	2	44233.58	676.56	<0.01
Org x session 2	46906.17	2	23403.08	358.72	<0.01
Error	1176.87	18	65.38		

iv) Av. label time

Source	ss	df	ms	F	Sig.level
Between subjects	247	11			
Organisation	10.75	2	5.37	0.2	NS
Error	236.25	9	26.25		
Within subjects	197	7			
Session	165.37	1	165.37	71.29	<0.01
Session x org	10.75	2	5.37	2.32	NS
Error	20.87	9	2.32		

v) Av. communication time

Source	ss	df	ms	F	Sig.level
Between subjects	140984.46	11			
Organisation	130208.33	2	65104.17	54.37	<0.01
Error	10776.12	9	1197.35		
Within subjects	5793	7			
Session	1536	1	1536	13.3	<0.01
Session x org	3217.75	2	1608.87	13.93	<0.01
Error	1039.25	9	115.47		

Simple Main Effects - Av. communication time

Source	ss	df	ms	F	Sig.level
Org x session 1	87184.2	2	43592.1	754.97	<0.01
Org x session 2	46246.04	2	23123.02	400.46	<0.01
Error	1039.25	18	57.74		

vi) Av. plot-report time

Source	ss	df	ms	F	Sig.level
Between subjects	130.11	11			
Organisation	56.52	2	28.26	3.45	NS
Error	73.59	9	8.17		
Within subjects	23.87	7			
Session	4.59	1	4.59	2.74	NS
Session x org	4.18	2	2.09	1.24	NS
Error	15.09	9	1.68		

vii) Av. pass time - Status Report

Source	ss	df	ms	F	Sig.level
Between subjects	16949.83	11			
Organisation	9722.33	2	4861.17	6.05	<0.05
Error	7227.5	9	803.06		
Within subjects	3812	7			
Session	3174	1	3174	71.95	<0.01
Session x org	241	2	120.5	2.73	NS
Error	397	9	44.11		

Tukey Multiple Comparison of Means - Av. Pass time - Status Report

Means: 110 Vertical
75.5 H. co-op
62.25 H.ind

	n=k=3		k=2	
	<0.05	<0.01	<0.05	<0.01
SR(n)	3.95	5.43	3.95	5.43
SR(k)	3.95	5.43	3.20	4.60
AvSR	3.95	5.43	3.57	5.01
S	2.35	2.35	2.35	2.35
WSD	9.28	12.76	8.39	11.77

b) Accuracy measures

i) No. contacts plotted

Source	ss	df	ms	F	Sig.level
Between subjects	1445.46	11			
Organisation	567.58	2	283.79	2.91	NS
Error	877.87	9	97.54		
Within subjects	804.5	7			
Session	759.37	1	759.37	154.01	<0.01
Session x org	0.75	2	0.37	0.08	NS
Error	44.37	9	4.93		

ii) No. wrong labels

Source	ss	df	ms	F	Sig.level
Between subjects	4053.12	11			
Organisation	547.75	2	273.87	0.70	NS
Error	3505.37	9	389.49		
Within subjects	588.5	7			
Session	135.37	1	135.37	3.49	NS
Session x org	104.25	2	52.12	1.34	NS
Error	348.87	9	38.76		

iii) No. correct reports

Source	ss	df	ms	F	Sig.level
Between subjects	451.33	11			
Organisation	71.08	2	35.54	0.84	NS
Error	380.25	9	42.25		
Within subjects	412	7			
Session	352.67	1	352.67	61.33	<0.01
Session x org	7.58	2	3.79	0.66	NS
Error	51.75	9	5.75		

iv) No. report errors

Source	ss	df	ms	F	Sig.level
Between subjects	483	11			
Organisation	37.75	2	18.87	0.38	NS
Error	445.25	9	49.47		
Within subjects	389	7			
Session	322.66	1	322.66	45.55	<0.01
Session x org	2.58	2	1.29	0.18	NS
Error	63.75	9	7.08		

v) SR Error - Actual/Screen

Source	ss	df	ms	F	Sig.level
Between subjects	913	11			
Organisation	273	2	136.5	1.92	NS
Error	640	9	71.11		
Within subjects	589	7			
Session	522.66	1	522.66	75.87	<0.01
Session x org	4.33	2	2.16	0.31	NS
Error	62	9	6.89		

vi) SR Error - Screen/Operator

Source	ss	df	ms	F	Sig.level
Between subjects	638	11			
Organisation	160.75	2	80.37	1.52	NS
Error	477.25	9	53.03		
Within subjects	142	7			
Session	16.67	1	16.67	1.81	NS
Session x org	42.58	2	21.29	2.32	NS
Error	82.75	9	9.19		

APPENDIX XIII

Categories of Communication (Krumm and Farina, 1962)

Category Number	Category Description
A	Requests information
	(i) factual data
	(ii) course of action
	(iii) opinion or evaluation
B	Provides information
	(i) factual data
	(ii) course of action
	(iii) opinion or evaluation
C	Volunteers assistance
	(i) factual data
	(ii) course of action
	(iii) opinion or evaluation
D	Order course of action
E	Formal indication of compliance to orders
F	Irrelevant remarks
G	Acknowledgement of receipt of message

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