SPECIAL REPORT

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SUMMARY

This report describes an experimental procedure designed to yield a step-wise break-down of mechanical jobs in terms of five categories, each of which represents a specific area of psychological functioning. The technique comprises two sequential parts, namely task description, where a detailed picture of task requirements is obtained and task analysis, where the psychological implications of the task requirements are determined. The analysis of a particular job is expected to yield information useful for the compilation of a specific test battery to select individuals whose pattern of abilities suitably match the task demands inherent in the job. It is intended that the procedure should serve as a supplementary companion to the NIPR job evaluation method, to be employed where additional job information is needed to introduce effective selection testing procedures.

OPSOMMING

In hierdie verslag word 'n prosedure beskryf waarvolgens die posinhoud vervat in meganiese tipes van werk stapsgewys onderverdeel word vir ontleding. Vyf gebiede van sielkundige funksionering word verteenwoordig deur kategorieë in terme waarvan die onderverdeling plaasvind. Die tegniek bestaan uit twee opeenvolgende dele, naamlik taakbeskrywing waardeur 'n gedetailleerde beeld van taakvereistes verkry word en taakontleding waardeur die sielkundige implikasies van die taakvereistes bepaal word. Die ontleding van 'n besondere betrekking behoort inligting te verskaf vir die saamstelling van 'n geskikte keuringstoetsbattery. Daar word beoog om hierdie prosedure addisioneel tot die NIPN se bestaande posevalueringsmetodes te gebruik in gevalle waar 'n baie gedetailleerde of omvattende metode vereis word.

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1. INTRODUCTION : THE NEED TO ANALYSE MECHANICAL JOBS INTO DIMENSIONAL COMPONENTS

In view of the increasing rate of mechanisation in industry and the concomitant demand for skilled workers in this domain, it is a problem of self-evident importance to identify the psychological properties of jobs which fall in the mechanical domain, and to devise selection procedures appropriate for South African conditions. Notwithstanding the considerable amount of literature and test material that has been assembled in this field, it is clear that agreement among various investigators as to the factors operating in mechanical task performance is not unequivocal. The experimental technique described in this report should be viewed against a background of four main problem areas.

1.1 Definition of the term "mechanical"

A mechanical job as the term is ordinarily used covers a wide variety of activities, ranging from those performed by unskilled labourer to graduate mechanical engineer. In view of the heterogeneity of work behaviour and the topographical dissimilarity of the numerous jobs that fall under the rubric "mechanical", no adequate *a priori* definition of the term exists, either linguistic or operational and it is generally employed in an intuitive way.

1.2 Theoretical approach

Approaches to the problem appear to be divided on the issue of whether mechanical aptitude is a *psychomotor* concept or a *cognitive* one. In this respect it is not uncommon for the verbally minded to regard mechanical aptitude as little more than some form of finger dexterity associated with a willingness to get one's hands dirty. Consequently, some investigators have emphasised solely manual aspects in their approach to the problem, and accordingly developed tests of psychomotor performance (e.g. Finger Dexterity, Reaction Time, Two Hand Coordination, etc.). Other researchers have referred only to the cognitive processes involved in solving mechanical problems or executing mechanical tasks (e.g. Mechanical Comprehension, Spatial Reasoning, Perceptual Speed, etc.).

1.3 Measurement difficulties

It is often emphasised in the literature that more than a single factor is needed to account for mechanical task performance and to predict vocational success. Traits such as general intelligence, temperament and physique, together with interests, motivational variables and previous training may assume a larger rôle in task performance than any specific ability. In addition to the problem of selecting suitable predictor measures, the heterogeneity of the field poses the problem of selecting useful and relevant criteria of mechanical performance. The criterion problem is one which has led many investigators to restrict their research to recording the intercorrelations of batteries of so-called mechanical aptitude tests, and subsequently determining their factorial composition, rather than relating tests to specific on-the-job mechanical performance.

1.4 Semantic inconsistencies

Considerable disagreement exists with respect to the terminology and nomenclature used by different researchers. The terms "aptitude", "ability" and "skill" are frequently employed as if they were synonymous, which leads to difficulty when an attempt is made to compare one set of findings with another.

1.5 Theoretical framework of the study

In view of the problems noted above, a brief note is felt to be warranted, noting the theoretical basis of the project.

1.5.1 Mechanical aptitude

This is viewed as a general term describing an individual's capacity to achieve superior performance on mechanical tasks. It is assumed that mechanical aptitude is not a unitary variable, but consists rather of a number of relatively separate, independantly definable abilities. Performance on mechanical tasks is seen as drawing upon a combination of these intellectual and/or psychomotor abilities. As a starting point, one may note that certain kinds of work (specifically work involving the manipulation of tools, the operation of machinery, and the planning and execution of tasks that involve these activities) can broadly be classified as "mechanical" jobs. Bennett and Cruikshank (1942[1]) have proposed that such work can be classified further in terms of three fairly distinct components or categories.

(a) A cognitive/intellectual component involving the capacity for understanding mechanical relationships. This probably encompasses the elements of general intelligence, spatial ability, inductive and deductive reasoning together with specific mechanical knowledge or training. High degrees of this component are seen as characteristic of engineers and physical scientists.

(b) Manual dexterity or manipulative skill. This is held to involve precision and judgement of muscular responses, and coordination of perceptual input information and motor output. The lower extreme of this trait is seen in birth injury cases, where the individual is unable to carry out such simple tasks as brushing the teeth.

(c) Gross motor abilities of strength, speed of movement and endurance. These capacities are often utilised in unskilled jobs, particularly those concerned with movement of materials. Mechanical occupations are assumed to require the possession of all three components, while their relative importance varies widely (i.e. successful performance on mechanical task X draws upon a weighted combination Y of different abilities from each of the above three categories).

1.5.2 Mechanical ability

Following on from the above statement, the term "ability" is used to refer to a more specific trait of the individual. This is inferred from certain response consistencies on particular types of tasks (or tests). The human adult is assumed to have many different abilities, which are fairly stable traits not subject to very much change over time. Thus an individual is not strictly described as having mechanical ability. Rather, the person who demonstrates superior performance on mechanical tasks may be thought of as possessing the various component abilities of the complex known as mechanical aptitude.

1.5.3 Mechanical skill

The term "skill" is used to refer to the level of performance an individual achieves on a specific task or related group of tasks. It is a task oriented rather than an individual oriented concept. The notion is that a skilled worker is one who has acquired through overlearning, the coordinated integration of appropriate response sequences required to deal with a set of criterion tasks. Unlike abilities, skills are assumed to undergo considerable alteration over time as a result of retention loss, positive or negative training transfer, etc. At the risk of labouring the point, the adopted meanings of the above three terms may be summarised thus : It is assumed that an individual with mechanical <u>aptitude</u> is one who possesses the required complex of component <u>abilities</u> and consequently the capacity to be quickly and efficiently trained to some criterion of <u>skilled</u> responsiveness.

1.6 The objective of the present study

In line with the conceptual formulations above, it was decided that the goal of determining the essential nature of mechanical aptitude would best be served by the <u>empirical</u> identification of the <u>component abilities</u>

required for mechanical task performance. The conclusion was reached that this objective would best be achieved by the procedures of job evaluation and a systematic analysis of a sample of mechanical jobs. The method of analysis described below was finally arrived at after a considerable period of trial-and-error and adaptation.

Task analysis may be simply defined as a structured observational technique used in systematically breaking a job down into its component tasks and operations. The procedure is one which permits inferences to be drawn regarding the psychological demands made upon the worker, by the individual tasks that he is required to perform. The primary goal of task analysis in the present context is the development of a taxonomy of such task demands. The notion is to identify from the taxonomy the basic abilities underlying the performance of a mechanical job, with the hope that this will lead to the compilation of the most economical and useful battery of selection tests.

To re-iterate, the technique of task analysis described below is an attempt to develop a taxonomy of human performance based on a method of systematic observation in the actual work situation. The goal is the demarcation of mechanical aptitude components, identifiable in terms of the psychological processes involved.

A number of different methods of dividing a job into its components are currently available. However, in searching for a theoretical basis for the present study, it was felt that two existing task analysis techniques possessed attributes particularly suitable for the present research objective. The first method may be referred to as "Category-specific" task analysis and was developed in the USA by Miller (1962[2], 1971[3]), for the purpose of assisting in the making of "system design" decisions (e.g. in the areas of Training, Job Design, Selection and Ergonomics). The second procedure, known as "Hierarchical" task analysis, was developed in the UK by

Annett and Duncan (1971[4]) specifically to yield information useful for decision making in the area of worker training.

In view of the fact that task analysis had not been employed in any previous NIPR projects, the present pilot study was undertaken to test the usefulness and efficacy of the approach. Certain attributes were taken and adapted from each task analysis technique and incorporated into a single method for the collection of job-content information. A number of visits were paid to an engineering firm and to the NPRL in Pretoria for this purpose.

2. THEORETICAL BASIS OF THE TECHNIQUE

The technique is applied in two parts. Firstly an effort is made to obtain a total picture of task requirements. This stage is called task description. Secondly, an attempt is made to discover the behavioural and psychological implications of these task requirements. This part of the process is called task analysis.

It must be emphasised that certain difficulties are encountered when attempting to describe the adopted method in a short space as its basis is a complex cognitive information-processing theory of human performance. (Plans in the structure of behaviour. Miller, G.A., Galanter, E. and Pribram, K.H., 1960.) A summary of the theoretical orientation is attempted in the form of three briefly described assumptions. Two assumptions pertain to the task description stage and the third to the task analysis process. The theoretical position will hopefully be clarified by an account of the technique's practical application, which follows below.

2.1 Task description

2.1.1 Assumptions

The procedure of describing the tasks within a job is based on the following assumptions :

<u>The first assumption is that human activity or job behaviour can best be defined in terms of its objectives or end products.</u> That is to say, in describing work behaviour, attention should be focussed not so much on the specific movements that are made, but rather on what is achieved. The most important aspect of work activity is its goal or end product. For example, in driving a car there are a variety of objectives that can be stated, such as <u>speed, safety</u> and <u>economy,</u> etc. The tasks of winning a race and winning an economy trial are different because the objectives (speed and economy) are different.

<u>Work performance is assumed to consist of a number of identifiable units of behaviour, where each unit consists in turn of a number of hierarchically arranged sub-units.</u> The terms unit and sub-unit in this context are not used in a quantitative sense, but refer to behaviours which can be identified in terms of assumption one. Assumption two may be illustrated by considering the behavioural unit "driving a car" as consisting of the sub-units "scanning the road", "turning the wheel", "engaging the gears", etc. In similar fashion, the behavioural sub-unit "engaging the gears" can conceivably be broken down or more specifically described in terms of even <u>smaller</u> behavioural sub-units, e.g. "releasing the accelerator", "depressing the clutch", "grasping the gear lever", etc.

<u>2.1.2 Hierarchical structure of a job</u>

The reference to a <u>hierarchical</u> relationship may be clarified by introducing the terms SEGMENT, TASK and OPERATION as defined below (see also Figure 1).

(a) A JOB is assumed to consist of a collection of work activities or behaviours defined in terms of a goal. The goal implies the objective of the system in some real terms of production units, quality, services or other criteria.

(b) The JOB can be broken down into a number of SEGMENTS, each defined by a sub-goal, again measured in real terms to overall system output and therefore measurable in terms of performance criteria. The set of segments, viewed in chronological order may be seen as constituting the job cycle.

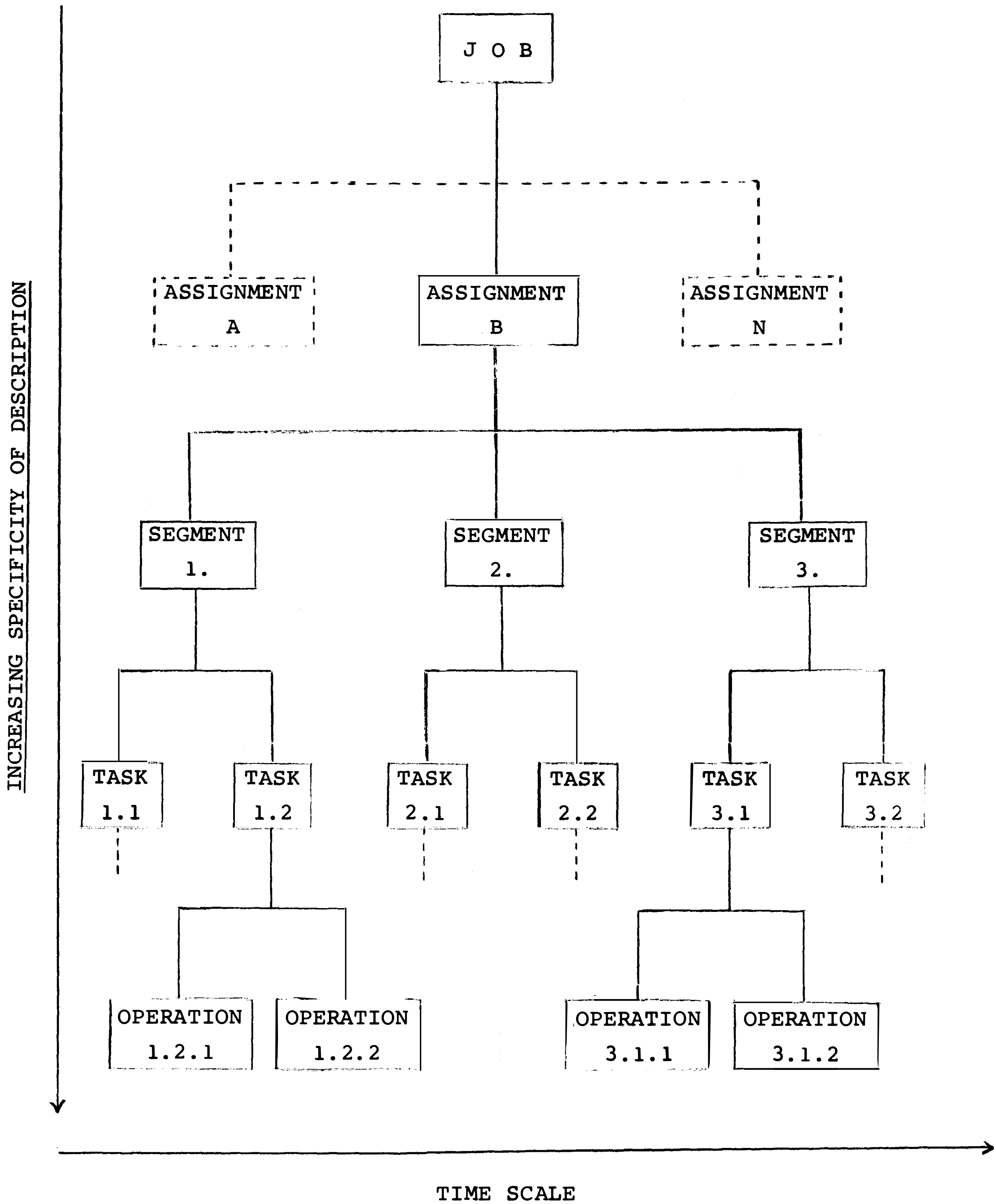
(c) Each SEGMENT can be broken down conceptually in the same manner into a number of TASKS, which in turn may consist of one or more OPERATIONS. The term operation is introduced to stand for the smallest unit of behaviour which can be defined in terms of its objective. An arbitrary set of movements, however precise is not an operation unless the end product or objective can be specified.

(d) The important relationship between superordinate and subordinate units is one of inclusion. It is a hierarchical relationship in which behavioural specificity increases as the description of JOB content proceeds to the level of TASKS and OPERATIONS.

Although the theoretical basis of task description is the hierarchical structure outlined above, such a paradigm would be too unwieldy for the actual collection of task description information. Information is recorded instead on a special task description form by the investigator who observes the incumbent working for a time and subsequently follows this with a short interview. Time required for the collection of information ranges from 20 minutes to a number of hours, depending upon the complexity of the job being described.

Task descriptions are simply accurate specifications of human performance required for particular tasks. These specify along an "information-flow" time scale the environmental cues which the human operator should perceive and the related responses he should make in the work environment.

2.1.3 Schematic representation of job structure



2.1.4 The procedure of collecting task description information

(i) General job cycle statements. The job cycle is first described by half a dozen or so short statements which follow the sequence of major events in a typical mission or assignment, e.g. "Inspection of vehicle", "Loading of freight", etc. Each of these activities may be called a SEGMENT in the job cycle. (Clearly higher-level, non-repetitive jobs will involve participation in more than one kind of assignment. Consequently, each different assignment will consist of its own set of job cycle segments.) Other information recorded as part of the general job cycle statement include :

- major environmental conditions prevailing in each segment
- notable segment features such as the degree of gross bodily movement involved
- the extent of external pacing of the activity

(ii) Detailed description. The job cycle statements are used to facilitate identification of tasks, task clusters and their relationships. Each segment in the job cycle is assumed to consist of one or more tasks, where a task may be defined as a series of goal-directed operations by a human operator of a prescribed set of tools, through a set of completely or partially predicted environmental states. Each task within a segment is assumed to have a specific goal - which is in turn a sub-goal of the segment in which it occurs.

The next step is to describe the specific behaviours within the tasks. Each task is assigned for convenience a number which codes its position on a time scale within each job segment. (See schematic representation.) Information regarding each task activity is noted on the task description form according to the following "information flow" model :

(a) The INDICATION, which is any signal which calls for a work response (i.e. any source of information which establishes a difference between a present condition and a goal condition). The indication may appear all at once or may have to be assembled by the human by means of recall through periods of time. The INDICATOR may be any object or event on which the activity relevant indication appears that provides the response cue (e.g. a visual display).

(b) The CONTROL OBJECT to be manipulated, e.g. lever, spanner, etc. Where a task requires more than one operation, each of these is coded chronologically in the task sequence, e.g. "screwdriver - turn" "spanner - tighten", etc.

(c) The INDICATION OF RESPONSE ADEQUACY or FEEDBACK. This may be proximal, e.g. the feel of a toggle switch that has been moved, or a sweep-face visual display ; or distal, e.g. hearing a motor starting up. Further, feedback may be immediate or delayed and may consist in some cases of the worker having to combine information from a number of different sources across different sensory modalities. In many routinised tasks, the feedback from one step or activity is the indication for the next step.

(d) In addition, in order to get a proper picture of task complexity, two additional kinds of information should be recorded. (1) The kind of disturbance and irrelevance (perceptual noise) which can make the indications difficult to detect and identify. (2) Time sharing of activities. Time sharing activities are those performed at about the same time, and which have overlap in cues that must be searched for, remembered and acted upon.

PB

2.2 Task analysis

The task description provides the source information for the analysis which focusses on behaviourally important variables and attempts to relate these to what is known about ergonomics, abilities, learning, perception, etc. Task analysis can be taken to the point where an inference is drawn from the smallest identifiable unit of some operation ("turning a knob" for example). However, despite the careful, accurate and objective methods employed in task description, one should not cherish the illusion that task analysis satisfies all the canons of scientific rigour. It is clear that the move from the physically descriptive to the behaviourally analytic contains elements of subjectivity, intuition and judgement.

2.2.1 Sources of task difficulty

In the performance of any task cycle it is assumed that there are four "sources of difficulty" (Miller, 1971[5]) which may be noted on a time scale :

PERCEPTION ----→ DECISION ----→ RESPONSE ----→ FEEDBACK

After tasks and operations have been identified, these are analysed by "codifying" the psychological processes which intervene between input events from the work environment and outputs in the form of work responses. Miller's task analysis rationale is based on the premise that any group of activities - or collection of tasks, however complex, is related to a system goal. For this reason, no matter how heterogeneous tasks may be, one can generally find among them a common psychological structure. If one disregards the specific stimulus and response content of a large group of tasks, one generally finds that tasks differ from each other in terms of the relative weighting of the factors in this structure.

2.2.2 Categories of psychological functioning in work situations

Miller's structure consists of a number of "functional categories" where each category corresponds to a psychological function which is taxed or used in the operator by the activities that he performs. Analysis of individual tasks consists of a detailed annotation and classification of task content in terms of each category. As Miller views the evaluation process, this is accomplished by using the "bodies of knowledge" in experimental psychology assembled over the decades. A list of his categories and sub-categories appears below.

1. GOAL ORIENTATION AND SET
2. RECEPTION OF TASK INFORMATION
   Search and Scan
   Identification
   Noise Filtering
3. RETENTION OF TASK INFORMATION
   Short-term retention
   Long-term retention
   Memory for codes
4. INTERPRETATION AND PROBLEM SOLVING
   Stimulus variables
   Classes of response option
   Goal priorities
   Rules for selecting responses to problems
5. MOTOR RESPONSE MECHANISMS

It is clear that the above task structure categories are inevitably part of every task and certainly of every job. Some tasks may have a high degree of one or more of the factors present. For example, vigilance tasks have a high loading on search, scan and identification factors. In analysing tasks and attempting to tease out the abilities required for successful performance, it is clear that the investigator should make reference to "established bodies of knowledge" in these particular category areas, e.g.

knowledge concerning human performance on scanning tasks, signal interpretation, noise filtering, motor performance, etc. That is to say, existing systems used for the classification of psychological traits, especially abilities, forms the basis of the identification and grouping which takes place in the analysis.

3. APPLICATION OF THE TECHNIQUE

During the pilot study, the method of analysis was altered and refined after experimental investigations involving fifteen different jobs of varying complexity. Two examples are provided below. These represent practical attempts to apply the aforementioned method.

3.1 Example One

POSITION : PRESS OPERATOR

The incumbent has the responsibility of correcting the faults in a variety of heavy metal beams which reach him from the welding section. The latter process tends to result in a bending or twisting of the metal, which has to be straightened to conform to specific tolerance specifications, before the components can be sent on for assembly. The operator has at his disposal a pneumatic hoist and track, with which to manoeuvre the beams, and a hydraulic press and table, upon which he effects the straightening process. Stringent criteria of "straightness" are laid down, with which the worker's performance is compared.

ASSIGNMENTS :

1. Beam straightening.
2. Grinding.
3. Spot welding.

JOB CYCLE STATEMENTS

Segments : Beam straightening.

1. Input - Pick up beam from supply cradle and prepare for straightening.
2. Straighten - Operate press and straighten bends (present because of previous welding process).
3. Test - Check for straightness on testing table. Re-straighten sub-standard beams.
4. Output - After passing test put beam in output cradle.

Conditions

1. Continual noise from other workers hammering, drilling, cutting, etc.
2. Hot (about 30°C) intermittent high intensity light flashes from neighbouring welders.
3. Beams are heavy (± 60 kg), main movements of pushing, guiding. Discrete and serial motor responses.

The task description is presented in tabular form on the following pages.

Segment Number and Task	Time (in s)		Indication and when to do Task	Control object and operation	Feedback Modality and Indication of response adequacy	Remarks, Alternatives and/or Precautions
	In	Out				
1.1 Select input beam and couple to hoist chain.	0	1	Beams piling up in cradle from welders.	1. Overhead air hoist. Pull left control to lower. 2. Chain. Fasten to beam by clasp.	Visual. Satisfactory inspection chain in middle of beam.	
1.2 Lift beam onto table by operating air hoist.	1	2	Observation that chain secure and beam balancing.	1. Hoist controls. Pull correct handles. (Left = lower right = raise). 2. Push hoist beam along track maintaining balance with hands.	Visual and kinaesthetic. Beam balancing horizontally $\pm$ 5 m. above head. Beam moving towards criterion spot on press table.	Time sharing of hoist controls and visual inspection of moving beam. Heavy. Potential damage and injury.
1.3 Position beam on straightening table.	2	4	Beam in place over criterion marking and $\pm$ 5 cm above table.	1. Unclasp chain manually. 2. Tighten vices by hammering.	Visual and kinaesthetic. No movement of beam judged by tightness of vices.	Poor judgement of weight/distance could result in beam falling.
1.4 Detect bend spots and place blocks in place.	4	6	Beam secure on table. Recall type of bend expected from knowledge of type of weld previously executed. Search for bend.	Place block under bend spot and secure manually.	Visual. Block in middle of bend and directly below press hammer.	Operator must know different bend characteristics, which depend on 1. type of weld process, 2. thickness of metal, 3. criteria of accuracy required.

Segment Number and Task	Time (in s)		Indication and when to do Task	Control object and operation	Feedback Modality and Indication of response adequacy	Remarks, Alternatives and/or Precautions
	In	Out				
2.1 Operate press lever.	6	8	Block below hammer and secure.	Vertically moving handle. Pump repeatedly. Pressures required increase as hammer descends.	Visual. Hammer makes contact with straightening block. Kinaesthetic. Judgement of how hard to press (depends on severity of bend).	Operator can't articulate criterion, but 'knows' how hard to operate press from accumulated experience. Error results in time waste and possible damaged equipment.
2.2 Release press hammer and proceed to next bend spot.	8	10	Hammer retracts. Perceive next bend spot and judge severity.	Chain and hoist as above. Carefully manoeuvre beam with minute hoist adjustment.	Visual judgement. Three variables. 1. Position of beam on table. 2. Position of blocks. 3. Relative position of bend.	Time sharing accurate judgement of bend spots while operating overhead hoist.
2.3 Operate press hammer as above.	10	15	4-6 times per beam.	same	same	Severity and place of bends change substantially across beams. Requires changes in application of operations.
3.1 Move beam to test table and secure.	15	17	Completion of hammer operation, i.e. block reaches end of beam.	1. Hoist control operations. 2. Pushing of beam along track. 3. Balancing of beam all as above.	Visual and kinaesthetic. Beam level on blocks on test table.	

Segment Number and Task	Time (in s)		Indication and when to do Task	Control object and operation	Feedback Modality and Indication of response adequady	Remarks, Alternatives and/or Precautions
	In	Out				
3.2 Check with T square.	17	18	Beam secure. Perception of spots where straightening has taken place.	T-square. Position on table surface and beam face.	Visual perception of angle of T square and beam face. Check with memory of criterion tolerances allowed.	Different criteria for different beams.
3.3 Mark spots for restraightening.	18	19	Completion of first check.	Chalk. Marks on spots notsatisfying the criterion.	Correct coding of bend severity, i.e. *=slight bend, ***=severe bend, etc.	
4.1 Restraighten beams not acceptable	19	24	On basis of check results usually ±1/3 beams require restraightening.	as above.	as above.	
4.2 Place acceptable beams in output cradle.	24	26	as above.	as above.	as above.	

TASK ANALYSIS

(a) GOAL ORIENTATION AND SET

The major goal conditions are clearly defined and are relatively invariant. Behaviour is directed towards achieving an acceptable measure of straightness within the defined tolerances. Unidimensional measure (i.e. angle of deviation of T square from 90^{o}) is used. Sub-goals are input, straightening, test and output. These are sequential. Response alternatives are minimal.

Motivational context. Performance is initiated and paced by the degree to which beams are piling up in the input cradle. The speed of the required performance can vary, although the sequence cycle remains unchanged. The operator must be consistently alert and vigilant to satisfy safety requirements, in view of the size and the weight of beams and the possibilities of accidents.

Performance criteria. These may change within fairly narrow limits, depending upon the composition and properties of the beams. Possible measures of performance effectiveness are (1) the proportion of the beams that require restraightening, (2) the average time taken to achieve each sub-goal, (3) the average output per day.

(b) RECEPTION OF TASK INFORMATION

Task relevant cues are predominantly visual, e.g. tasks 1.1, 1.2, 1.3, 2.1 require simple search and scan operations involving the ability to estimate size (area and volume) and distance. Workers must scan a fairly large work-space (approximately 5mX5mX3m) and judge relative distances separating large, regular objects. Tasks 1.4, 2.2, 3.2 involve special identification of bend-spot characteristics (i.e. the angle of deviation of the metal surface from 180^{o}). This requires visual acuity together with the ability to make discriminations between visual inputs. (Unidimensional, i.e. degree of straightness of a single plane).

Secondary task relevant cues are kinaesthetic, e.g. 1.2, 1.4, 3.2 involve the kinaesthetic estimation of movement and relative pressure (balancing). Loading on this factor is low and it exists rather as a subsidiary check on the more predominant visual inputs.

(c) RETENTION OF TASK INFORMATION

Short-term tasks appear to have a high loading on short-term visual memory (STM), particularly tasks involving the movement of the beam by means of the hoist. (Similar STM demands involved in driving a car). In tasks 1.3, 2.1, 2.2 the operator is required to perceive and store the configuration of beam, hoist-track and table. This involves the ability to "visualise" the relative positions of 3 simple shapes in space while attending to other perceptual inputs. The time-shared operation of hoist-controls requires the operator to be able to store short-term kinaesthetic information (kinaesthetic distance). This is not an essential factor. If the operator does not store this information, he must employ an alternative strategy of rapidly scanning the work-space and storing the visual inputs, i.e. a greater load is placed upon visual discrimination and memory. Task 1.4 requires more detailed visual STM for form. After the operator has located a bend fault he must be able to (1) retain in STM its relative position on the beam (2) the angle of the bend (i.e. severity of the fault).

Long-term memory (LTM) tasks 1.4, 3.2, 4.1 involve the ability to recall a set of standards or procedures, i.e. (1) the characteristics of bend faults caused by particular types of welding, (2) the appropriate degree of force to be applied to the hydraulic hammer, (3) the criterion or maximum permitted deviation of the T square from 90^o. The latter requires the operator to have an LTM "template" or visual image of the standard which he can recall when required. Emphasis is on the LTM of simple visually presented forms.

(d) INTERPRETATION AND PROBLEM SOLVING

The majority of the tasks require simple, discrete or serial motor operations on the basis of the identification and interpretation of visual (predominantly) and kinaesthetic inputs, namely length, breadth and curvature of regular shapes. The operator adheres to a sequential pattern of responses. No strategies are required for selecting qualitatively different response classes. The operator must be able to select a quantitative value of response adequacy (2.1 the degree of force to be applied to the hammer control). The operator infers this value on the basis of his perception of 3 other variables : (1) the severity of the bend, (2) the criterion tolerances required, (3) the thickness of the metal. It is assumed that rapid training of an operator to a level where he can apply the appropriate rule, requires a reasoning ability of at least average level (in comparison with a norm group of black workers).

1.1 - 2.1 The learning of appropriate scanning strategies and the ability to combine sensory inputs from more than one modality are assumed to require mental alertness or general intelligence of a certain level.

(e) MOTOR RESPONSE MECHANISMS

Tasks 1.1 and 1.2 involve the gross body movements of pushing, pulling and manoeuvring a heavy object. A certain amount of physical strength is required. In 1.3 there is a small component of two hand coordination and finger dexterity. This probably falls within the capacity of the majority of the population. It is consequently unlikely to serve as a basis for an effective selection instrument. The operation of a handle in task 2.1 requires the ability to judge the required application of pressure or force. Poor judgement would result either in wasted effort, or an increase in the proportion of beams requiring restraightening. Again this task requirement of kinaesthetic discrimination is felt to be within the capacity of the majority of the population. The majority of motor responses are simple, discrete or serial movements requiring physical strength and are dependent upon an appropriate interpretation of visual inputs for their effectiveness.

SUMMARY OF ABILITIES REQUIRED

1. The heaviest loading is on the ability to perceive the relative positions and sizes of 3 simple regular shapes in 3-dimensional space.
2. The ability to make discriminations between visually presented stimuli which vary in terms of the amount of curvature is also necessary.
3. Another required ability is that of being able to store or "visualise" information from 1 and 2 above in short-term memory.
4. Average reasoning ability and general intelligence is needed.
5. Physical strength is an important factor.

3.2 Example 2

POSITION : APPRENTICE OPTICIAN

This study was undertaken in view of a possible new project concerning the selection and utilisation of apprentice opticians. It should be stated that the process of lens manufacturing is an involved one, requiring up to two weeks for the completion of a single job cycle.

Although this process may be divided into eight job-cycle segments in accordance with the method outlined above, a detailed analysis was conducted on only one segment (lens polishing) for the purpose of this study.

Below is a brief description of each job-cycle segment, followed by the more detailed description and analysis of the lens polishing segment.

JOB CYCLE SEGMENTS

1. Slide cutting : Blocks of optical glass (or other material) are cut into slides of a certain thickness. Dimensions of slides depend upon the anticipated size of the finished lens. Cutting is achieved by means of a diamond impregnated circular saw, electrically operated.

2. Round shaping : Slides are cut into circular discs of a particular diameter. This is achieved by means of a round-grinding machine on a hand bench.

3. Core drilling : This is an alternative to the above procedure. A core or cylinder of optical glass is drilled out of the initial glass block using a special drilling machine, with a diamond impregnated bit. The core, which must be of a specified diameter, is cut into round discs as above, using the slide cutting machine. Different substances require different drilling procedures.

4. Milling : The circular disc is now processed in the milling machine which shapes the optical disc to the particular radius of curvature, as accurately as possible within mechanical tolerance limits (measured in microns ; 1 micron = 0,001 mm). This process takes into account (a) the type of optical material and its properties, e.g. hardness, brittleness, reactions to heat, etc., (b) the initial diameter of the disc, (c) its thickness, (d) the intended radius of curvature, and (e) whether concave, convex or flat, etc.

5. Grinding : This segment marks the first step from where the lens moves from mechanical tolerance limits to optical tolerance limits (the latter are measured in Newton-fringe units, where 1 NF = 0,00015 mm). This is accomplished by a human operator on a hand-wheel. The operation is intended to smoothe the lens surface, i.e. remove pitting and scratching resulting from the machine process.

6. Lapping : A recent innovation which can to some degree

replace grinding (much more rapid process). An abrasive "lapping cup" is rotated over the lens mechanically and smoothes the lens surface in a similar way to the grinding process above.

7. Lens polishing : After grinding has removed the gross surface irregularities from the surface of the lens it is "polished" on a pedal operated hand-wheel until it meets the required specification criteria. This particular job-cycle segment presents a selection problem as it has been found that fewer than 5% of individuals recruited for the position of optician can be successfully trained to complete this process.

8. Final checking : After the polishing process, the finished lens is subjected to final checking on a number of different electronic measuring devices.

The task description (segment 7 only) is presented in tabular form on the following pages.

Segment Number and Task	Time (in s) In	Time (in s) Out	Indication and when to do Task	Control object and operation	Feedback Modality and Indication of response adequacy	Remarks, Alternatives and/or Precautions
7.1 Apply woodpitch to curved surface of polishing wheel.	0	3	Completion of segment 6. Start of polishing procedure.	Small trowel and putty knife. Knead and shape.	Visual inspection that woodpitch even and uniform thickness of ± 3 mm.	Different polishers have different preferences regarding thickness of pitch. Depends on strategies adopted (see below).
7.2 Apply polishing rouge to woodpitch surface.	3	4	Following satisfactory visual inspection of wheel surface.	1. Dilute polishing rouge with measured quantity of water. 2. Paint brush. Apply to uniform thickness.	Visual inspection. Rouge uniform colour and evenly distributed.	Abrasiveness of rouge = $\frac{1}{\text{water content}}$. Different degrees of abrasiveness for different optical substances.
7.3 Apply lens to surface of woodpitch and rotate wheel.	4	6	Rouge coating correct colour and wetness.	1. Lens handle 1,5cm long. Held in index finger and thumb of both hands. 2. Pedal. Foot operated to make wheel spin.	Absolute and relative pressure on lens handle correct. Wheel spinning at correct speed.	Pressure and speed depend upon the chosen polishing strategy - see below.
7.4 Execute polishing movement.	4	6	Continue from 7.3.	1. Lens handle. Execute sweeping figure '8' motion by wrist and arm movements. 2. Maintain or modify pedal speed.	Kinaesthetic feedback that pressure and movement extent correct. Kinaesthetic judgement of degree of resistance afforded by rouge. Correct frequency and amplitude of sound emitted by process.	Time sharing. Required to aggregate information from a number of sources. As rouge becomes dryer resistance greater.

Segment Number and Task	Time (in s)		Indication and when to do Task	Control object and operation	Feedback Modality and Indication of response adequacy	Remarks, Alternatives and/or Precautions
	In	Out				
7.5 Clean component and Test Plate.	6	10	Response adequacy cues in 7.4 after ± 2 minutes of polishing.	1. Sponge. Wipe component under water and inspect. 2. Alcohol and special cloth. Clean thoroughly. 3. Fine brush. Invert test plate and component and sponge off.	Visual inspection absence of rouge residue. Perceived as uniformly clean. <u>Absolutely</u> free of dust.	Laborious but important procedure. Dust causes scratches and damages test plates. Ruins ±2 weeks of work. Expensive.
7.6 Place component and test plate together and test accuracy of fit.	10	12	Satisfactory visual inspection.	1. Graded finger and wrist movements. 2. View fit under monochromatic light source.	Visual. 1. Count number of Newton-fringe lines. 2. Judge angle of curvature of lines. 3. Judge distance lines are apart.	NB. This is the diagnosis stage of lens polishing. Configuration must be remembered and the appropriate strategy adopted.
7.7 Start polishing as in 7.4 above.	12	15	1. Perception of fault on comparison with test plate, e.g. edges of comparison need more polishing. 2. Adoption of appropriate strategy.	1. Gasburner. Apply heat to woodpitch and thereby increase surface area. 2. Foot pedal. Increase rotation speed in order to polish edges more. 3. Alter stroke of polishing movement, e.g. shorter stroke polishes edges more.	1. Perception that wheel at correct temperature. 2. Visual estimation of correct distance. 3. Kinaesthetic judgement of correct distance.	Three variables. Heat, speed, stroke selected and combined to form a particular strategy.

Segment Number and Task	Time (in s)		Indication and when to do Task	Control object and operation	Feedback Modality and Indication of response adequacy	Remarks, Alternatives and/or Precautions
	In	Out				
7.8 Clean and test as in 7.5 and 7.6.	15	21	as above. This task occurs up to 200 times per job cycle.	as above.	as above.	
7.9 Start polishing as in 7.4.	21	24	Perception of fault on test plate comparison, e.g. centre needs polishing.	1. Knife, scrape pitch and change configuration. Remove pitch from edges leaving more on centre. 2. Lens handle. Change relative distribution of pressure. Exert more on centre. 3. Rouge. Change consistency. Make more abrasive.	Visual inspection. Judgement of form. Kinaesthetic judgement of (a) absolute pressure (b) relative pressure. Perception of measured quantity of water added and perception of rouge colour.	Three variables. Shape of pitch, relative force and consistency of rouge.
7.10 Clean and test as in 7.5 and 7.6.	24	30	as above. Diagnose faults as in 7.6 and adopt appropriate strategy.	as above.	as above.	

TASK ANALYSIS

(a) GOAL ORIENTATION AND SET

The major goal is the production of a lens, meeting specification requirements (diameter, thickness, angle of curvature, hardness, homogeneity, etc.). This has a lengthy process cycle and involves a number of sub-goals. Although goals are clearly defined and the sequence of performance is invariant, many different strategies can be adopted to achieve the same end result. In many cases, the technician will not complete the whole process and will pass the component to a second technician. In view of this co-ordinative interaction, absolute understanding regarding (a) goals and sub-goals, (b) nomenclature and (c) procedures is essential.

Motivational and personality context. The emphasis throughout the process is on accuracy rather than speed, (tolerance limits are measured in Newton-Fringe Units, where 1 NF = 0,00015 mm). Work is laborious and monotonous and personality factors are assessed as being important. A technician must have a high tolerance for frustration and the ability to sustain his attention on minute visual cues. Probably, an introverted, low aggression personality type is best suited.

(b) THE RECEPTION OF TASK INFORMATION

Task relevant cues from both indication and feedback sources are received through a number of sense modalities, although the loading appears to be greatest on visual perception. Tasks 7.1 and 7.2 require the ability to estimate the size (area, volume and length) of small, regular shapes.

Task 7.4 demands visual acuity and vigilance. The technician must be able to search and scan for the smallest speck of dust or rouge grit on the component surface. Failure would result in severe damage to the lens and test plate surface.

Number 7.6 is a much more demanding visual task. This "fault detection" task is the most important of the process cycle. A technician must be able to perceive and classify a two-dimensional configuration by noting the following test plate characteristics or variables : (1) the number of Newton-Fringe lines, (2) the relative position of lines on a test plate surface, (3) the distance that the lines are apart,and (4) the degree of curvature of the lines. It can be regarded as a complex visual information processing task involving the ability to perceive small changes in visual form.

Tasks 7.3, 7.4 and 7.7. An important factor in terms of the reception of task cues is the ability to combine the sensory inputs from more than one modality. Time shared input and feedback is received through the visual, kinaesthetic, auditory and tactile modalities.

(c) RETENTION OF TASK INFORMATION

Short-term : e.g. Task 7.6. The technician must be able to store an accurate trace of the test plate configuration and recall this information when executing his next polishing strategy. While it is clear that some information is coded and stored semantically, subsequent interviews with technicians support the hypothesis that an important factor is STM for complex visual forms.

In 7.3, 7.4 and 7.7, time-shared tasks involving sensory inputs into two or more modalities require one or more of the following : (1) a suitable strategy for dividing attention, (2) the ability to maintain information from one input modality in a short-term store while attending to another source, (3) a high speed of information processing.

Long-term : Successful task performance demands that the incumbent has stored (a) a specialised vocabulary or task nomenclature of some 30 technical terms and their meanings, and (b) a taxonomy or "diagnostic classification" of the main types of lens faults. This would appear to be a complex structure based upon the four test plate parameters mentioned earlier.

(d) INTERPRETATION AND PROBLEM SOLVING

Interpretation requires bringing some context of information to bear in addition to what is directly presented to the senses.

7.7 After processing the visual test plate configuration in terms of the fault taxonomy, and holding the configuration in a short-term store the technician must choose the appropriate strategy. This entails choosing one, or a combination of the response options available to him. The operator has six possible response options : to change (a) the configuration of the woodpitch, (b) the level of heat, (c) the speed of the wheel, (d) the length of the polishing stroke, (e) the consistency of the rouge, and (f) the absolute and/or relative application of force upon the component. The technician must firstly choose which of these response options he is going to employ and secondly choose the level or value of each variable. This is assessed as requiring both inductive and deductive reasoning ability of a high level, together with the ability to make fine perceptual discriminations.

(e) MOTOR RESPONSE MECHANISMS

Tasks 7.1, 7.2 and 7.5. The majority of motor responses involve simple hand, wrist and finger movements. These are generally unspecialised and are felt to be within the motor repertoire of the majority of the population, (they are unpaced and do not require a high degree of dexterity or manipulative speed).

7.4 This is the only task requiring any form of motor ability and skill. The operator must have the capacity to co-ordinate foot and hand movements, i.e. maintain a constant wheel speed by operating the foot pedal while simultaneously executing the polishing movements.

Further, the polishing strategy itself involves the ability to judge kinaesthetic distance to within very small tolerance ranges, ($\pm$ 2 mm). It also requires the ability to judge absolute and relative pressures exerted upon the component, to within $\pm$ 100 g, i.e. a high level of sensory discrimination is demanded.

The task appears to have a component of kinaesthetic memory. The operator must recall from previous experience which is the appropriate force to exert and where. Experimental evidence suggests that such recall is not adequately explained by semantic coding, and involves kinaesthetic imagery as well.

SUMMARY OF ABILITIES REQUIRED

The successful training of an individual to reach competence as an optician would seem to require a number of specialised abilities and personality characteristics :

1. A high level of mental alertness and reasoning ability.
2. The ability to make minute discriminations involving four variables, in a visually presented two-dimensional configuration. and the capacity to accurately store a short-term trace of this information.
3. The ability to make precise kinaesthetic judgements on the dimensions of (a) movement extent, (b) absolute force, (c) relative force.
4. The ability to combine perceptual information accurately from different sensory modalities. This may be an independent specialised ability, or may simply require a high level of general intelligence enabling the operator to develop an optimal sampling strategy.
5. The ability to sustain attention on an intricate although laborious task. Certain personality variables are assumed to be of importance here. While it is not possible to articulate these factors clearly, it is proposed that individuals with a high tolerance for frustration and a low hostility level would be best suited.

6. Computational accuracy involving the calculation of area, volume, mass, etc. using the appropriate formulae.

4. CONCLUDING COMMENTS

The above two analyses were chosen as examples for the reason that although the two jobs differ widely in terms of complexity, they are similar in the sense that each is a mechanical "fault finding" task requiring a work response to some perceived irregularity in visual input.

The technique appeared to meet with qualified success in terms of differentiating between the two jobs and "extracting" the ability factors required for successful performance. However, a number of limitations on the usefulness of the technique are apparent. (a) The process of description and analysis is a lengthy one, particularly in the case of non-repetitive jobs in which a large number of different assignments can be identified. Each assignment would require a separate analysis, or alternatively a sampling strategy would have to be developed, determining which assignments should be analysed. (b) The technique depends for its success in categorising psychological processes, on a clear delineation of input and output events. In the case of the majority of mechanical tasks, these factors are usually clearly in evidence.
(c) While the task description stage could conceivably be carried out by someone with relatively little training, the process of analysis requires considerable familiarity with psychological theory.

It is considered unlikely that task analysis will lead to the uncovering of some hitherto undiscovered "mechanical ability". However, it is expected to make the following contributions to test construction :

(a) The recognition of a need. Task analysis across a systematically chosen sample of jobs is more likely to discover areas which need the further development of selection instruments than are continued investigations into the factorial composition of tests.

(b) The development of viable criterion measures of mechanical performance. Since each task description is a "blow by blow" account of actual performance requirements, it seems plausible that these should facilitate the development of relevant criterion measures for validation purposes.

Finally it is felt that the technique of task analysis developed during this pilot study could be adapted without much additional effort, for wider use in other NIPR research projects in the areas of selection and training. However, extension of the area of application to higher or dissimilar job categories may require more time than can be expended within the framework of the present project. If such activities seem worthwhile, further research proposals will be put forward.

REFERENCES

Order of Appearance

ANNET, J. and DUNCAN, K.D. (1971) : Task analysis. Training information paper no. 6. London, Department of Employment. — 4

BENNETT, G.K. and CRUIKSHANK, R.M. (1942) : A Summary of Manual and Mechanical Ability Tests. New York, The Psychological Corporation. — 1

DUNCAN, K.D. (1972) : Strategies for analysis of the task. In : HARTLEY, J. (Ed.), Strategies for Programmed Instruction : An Educational Technology. London, Butterworth.

FLEISHMAN, E.A. (1954) : Dimensional analysis of psychomotor abilities. J. exp. Psychol., 48, 437-454.

MILLER, R.B. (1962) : Task description and analysis. In : GAGNE, R.M. (Ed.), Principles in System Development. New York, Holt, Rinehart and Winston. — 2

MILLER, R.B. (1971) : Development of a taxonomy of human performance. Technical reports nos 6 and 11. Washington, American Institutes for Research. — 3, 5