FIELD STUDIES OF THE COGNITIVE PROCESSES INVOLVED IN CONSTRUCTION ACTIVITY

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1. *INTRODUCTION*

The development of "smart" machines that can replace labour in the field component of general building and construction operations has long been a dream in the minds of people in the construction industry.

Over the 19th and 20th centuries the introduction of machines has dramatically increased productivity in industrial society. Generally though, these machines need humans to mind and direct them - to perform the sensing, data gathering and problem solving component of the work. Mechanisation to date has largely been concerned with the replacement of the physical component of labour with the intellectual component still being carried out by people.

With the advent of computers and the information processing industry there is now potential for the full and near full automation of the human component of physical tasks. Decision making and versatility can be seen in these machines to a variable degree. Smart machines i.e. those that can directly replace humans in individual operations have now begun to appear in manufacturing and in the construction sector. For example, the Atlas Copco robot drilling jumbo.

So far the complexities and abilities of the "human machine" have proven extremely difficult to mechanise. The functions that humans deploy and integrate with ease, such as data gathering, information processing and analysis, coordination and management of physical processes cannot be currently be matched singly, let alone in combination, by machine. Simply put, machines are not yet as versatile. Mechanisation of even trivial tasks in non-structured environments has been beyond the state of the art.

It is a belief of the authors of this paper that a major stumbling block in the development of versatile field machines to replace construction labour in general is a basic lack of understanding of just what a human does (in both the intellectual and physical sense) to solve a field construction problem. There seems to be an almost total absence of fundamental research into how and what human constructors do in physical problem solving. In fact the authors are unaware of any published papers in the construction field that deal with any human cognitive function at a rigorous level.

It is a contention of this paper that only when designers have a clear appreciation of what is involved in construction activity will they be able to devise machines capable of replacing the human in the execution of physical tasks.

In this context it is noted that field and general purpose construction tasks are generally considered to be qualitatively different from normal manufacturing tasks. They tend to be one-off, novel, mobile and complex rather than stationary, repetitive simple and on-going. Also they tend to take place in dynamic rather than regular environments. As a consequence they are generally considerably more complex to automate and industrialise than general manufacturing tasks.

It is recognised that most construction practitioners may believe that what happens in the mind of a construction worker while he is doing a simple task such as filling up a bucket is trivial but anyone who has ever tried to design a machine to emulate even an apparently simple human activity will recognise the immense complexity of the activity at both the intellectual and physical level.

The aim of this paper is to contribute to the understanding of the fundamental mechanisms of generalised physical problem solving as carried out by humans. It is hoped this will provide a base of knowledge that will assist in the development of new generations of smart construction machines.

2. *EXPERIMENTAL RESEARCH PROGRAM*

As part of a long-range program to understand the cognitive processes of construction workers the concept was developed of experimenting with real workers on real construction tasks. The idea was to take a genuine construction operation and replicate its execution using significant numbers of individual workers representative of the construction population at a large. The objectives of this research are threefold:

i. To study the problem solving process and to determine what actions humans take to affect a solution to physical problems in unstructured environments.

ii. To develop process models of the above activity that may be useful in developing machines with similar or part replacement capabilities.

iii. To develop specific prediction models of human behaviour by which such concepts as opimality and productivity may be explored. Further the validity of the behavioural models developed can best be checked by attempting to predict behaviour. This is in line with Popper's suggestion that the key ideas in science are prediction and the testable proposition.

The basic method used in this approach is to study in great detail the real behaviour of workers and hence try to infer the underlying cognitive processes from their overt actions. The aim is then to try and match the observed cognitive processes with existing knowledge and theories of human mental functioning.

2.1 *Initial task selection*

The initial task studied in this research program is a relatively simple one and is the one reported on in this paper. Very early on in this form of research one finds that real human cognitive behaviour is incredibly complex and cannot be adequately studied in macro-scale tasks. This complexity of behaviour has been recognised by a very large number of workers in this field (for example Refs. 1 to 7).

Once behaviour can be adequately explained on simple tasks then more complex work may be attempted. After considerable deliberation and reflection a materials handling task of some 10 to 15 minutes duration was selected as meeting the requirements of experimental simplicity without being viewed by the worker as being trivially simple. Also it has the feature of being exactly replicatable. A consideration was the idea that other researchers may wish to carry out similar investigations. Hence the ideas of geographical repeatability and international understandability were incorporated in the task design. A further requirement of the test task was perceived relevance. It should be recognisably "construction" not "manufacturing" and hopefully something very commonly done on sites throughout the world. In brief what was sought in the test task was a prototypical construction task which could be considered a "primitive" for construction generally.

2.2 *Description of the test program*

The research task consisted of the simple act of moving a set of "unknown" objects through a distance of some metres on a plane, level terrain. A binary choice of technologies was provided i.e in the selection of either manual carrying or the use of a builders wheelbarrow. This task was considered relatively generic over materials and distances. A variety of tasks, materials, and environments were considered before the final design for the task was determined.

2.3 *The concept of the experimental series*

Sixteen identical large sacks, each containing a mass of weight "W", were placed in the middle of a large, flat, hard surfaced, featureless area. The sacks were placed in an ordered array, upright and tied so as to hide all features of the contained masses. The only other object present on this featureless terrain is a builder's wheelbarrow. The position of this piece of apparatus could be set by the investigator at any distance, "x", from the array of sacks. The distance setting could be at any value from zero to a virtual infinity point of 100 metres.

A large number of workers were given, individually, the task of relocating this set of sacks to a new position a distance "d" away. Where "d" could be any number of metres. The worker could use any method available to move the objects. This included carrying the sacks individually or in multiples or going to get the wheelbarrow and thence carrying them singly or in groups. Thus for any given setting of x,d,w the worker has available to him a number of distinctive strategies. One set based around the carry option, the other based around the barrow option. Additional to these basic alternatives a variety of detailed alternatives are open to the worker to load the barrow. He can load it in small "carry" trips wherein he loads the barrow one or more at a time. Similar arrangements apply at the far end at the unload barrow phase. The barrow operation can hence be represented as a five phase operation - get barrow, load barrow by method 1 to N, push barrow with quantity q, unload barrow by methods 1 to N, return barrow. (note that this last stage is sometimes optional depending on the task specification). Stage two, three and four are repeated as necessary to deliver quantity Q.

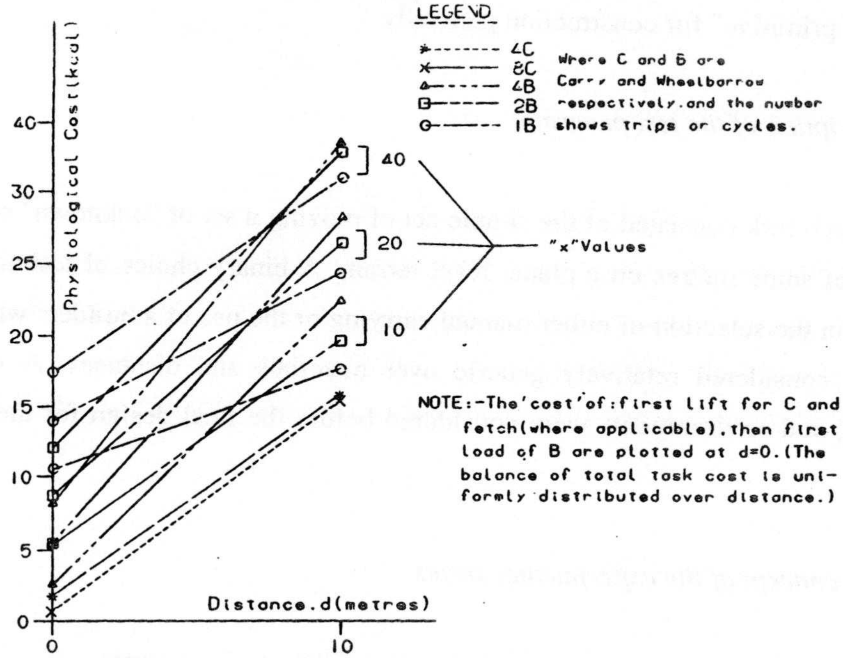

Figure 1. Options map for the research task

Figure 1 illustrates a basic options map for task execution. In this diagram the total physiological costs of the various strategic alternatives to move the 16 sacks is plotted for a particular weight W=14kg. The graphs were developed by carrying out a methods analysis and then applying physiological cost factors developed in ergonomics. The intercept on the Y axis of this graph represents the cost of getting and loading the barrow employing a specific method. This intercept distance in a particular case is a function of X.

For each value of W and d, a set of "cost" graphs such as these may be prepared from which a "best" option can be determined. Clearly in this style of experiment a large number of possible permutations and combinations of "w", "d", "x" are possible. Equally clearly the discovery of the optimal policy for the given data requires some process of calculation.

The aim of this experimental series, inter alia, was to observe which of the many options the worker actually chose and to discover insofar as it is possible how he arrived at his solution and how close to optimal if was. Thus for example, if the objects were heavy, "d" large and "x" small; one would expect the wheelbarrow to be employed. Did the bulk of workers actually do this? If the objects were light, "x" very large and "d" small; the worker would presumably carry the sacks. Does this predict real behaviour? Another question of interest is the worker's perception of the degree of difficulty of the "carry" and "barrow options and his perception as to the "investment" that could be justified in fetching the wheelbarrow.

2.4 *Experimental parameter settings*

For the set of experiments reported here a value of W = 14kg was selected as being an intermediate value for which a degree of uncertainty as to optimal strategy would prevail. Batches of workers were used at various settings of "x" and "d" with each group forming a statistical sample at that setting (albeit a small one). In the current experiment 57 workers were employed in batches of 9 or 10.

2.5 *Aims and Objectives of the series*

The experiment was set up with the following specific objectives:

- To ascertain whether the rationality postulate applies. i.e. whether people actively seek optimal policies and behave rationally. Would worker behaviour vary in any systematic way with variation of the job parameters. "x", "w", "d". If such a variation existed it could be taken as evidence that cognitive mechanisms are being used by workers to compute courses of action based on the parameters of the situation.

- To find out if the subjective thought processes correlated with the model of figure 1.

- To determine whether trends in behaviour are consistent with a process view. That is that a human problem solver adopts an invariant process in assessing or evaluating the job parameters and in solving a problem.

- Attempt to discover what sorts of calculations were being made by the workers and what data they were using. It was also hoped to find out how accurately the results of subjective thought processes matched up with the objective cost model of figure 1.

- To try to develop models of the cognitive processes being employed by the workers in this prototypical construction situation and to try to match these with established paradigms of human thought and problem solving as proposed by such people as Newell and Simon (Ref 1).

- To test some specific predictions associated with prototype theories.

2.6 *Data Collection and Methodology*

In an attempt to meet the aims above two means of data collections were employed:- Firstly, each worker had his actions recorded on videotape. Secondly, after the event each worker was asked to introspect and to say what he did and why he did it. Also a strict methodology for giving instruction was followed so as to eliminate hints, bias and presumption as to what the experimenter was seeking as the correct response. Instructions were given in written form as per Appendix C.

2.7 *Detailed Task Description*

The test task required a pile of sacks to be moved a distance of 5 or 10 metres from one position on a site to another. That other position was designated by a marker in the form of a witches hat. The situation is pictured in figure 2.

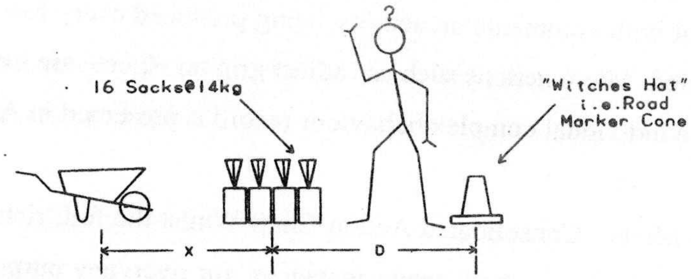

Figure 2. Schematic of the physical problem

Sixteen sacks were involved. Each was of woven polyethylene and contained a standard 150x300 mm concrete test cylinder. The bags were opaque. They were tied around the top to make relatively easily handled pieces. The objects were stockpiled in a standard array as illustrated in Figure 3. The wheelbarrow used was a standard rubber tyred builders model of about 0.1 cubic metres capacity.

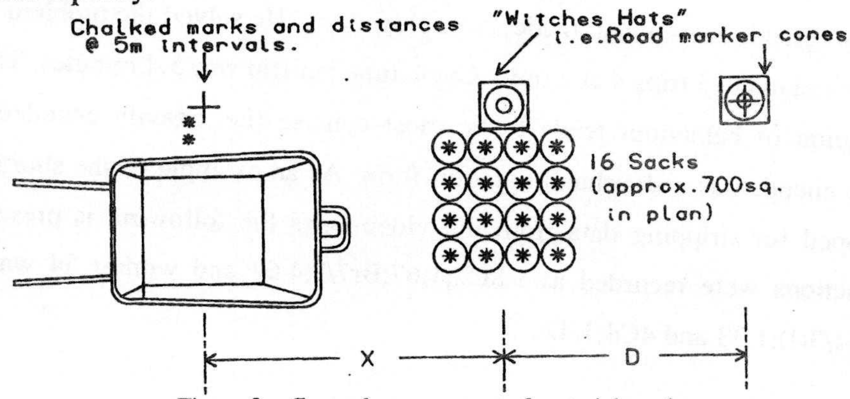

Figure 3. General arrangement of materials and apparatus

The "site" was the top deck of a large, effectively deserted, multi-storey car park.

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3. *RESULTS*

3.1 *Objective Results*

As a result of the comments of the human observer at the time and analyses of video tape, 57 individual behaviour dossiers were compiled to represent the unique and complex overt behaviours of each individual. The data can be presented in 3 forms.

i. Complex Behaviour Form In this form and individual's performance is recorded in micro-detail with comments on activity being produced every few seconds for the 10-15 minute period. Micro actions such as "adjust grip on object" are included here. A sample portion of a individual complex behaviour record is presented in Appendix A.

ii. Shorthand Mode - Consolidated Action Chart Whilst the full, rich complex behaviour of an individual is necessary in many instances, for overview purposes, a broader view is necessary. If one consolidates a large number of micro-activities into one macro activity, a broad bar chart type record can be produced of a worker's behaviour. This would have a time axis of minutes rather than seconds. An illustrative record is given in appendix A.

iii. Shorthand Mode - Strategy Language Description As an alternative to the above, an individual's behaviour can be described in verbal form using language that represents the strategy (grand, operational, tactical) employed. eg. He solved the problem by use of the barrow and made 3 trips 4 at a time. Cycle time per trip was 5.4 minutes. This method of description of behaviour tends to be most concise (i.e. heavily encoded). It can be further encoded as a shorthand notation form. As an example of the shorthand notation developed for stripping data from the video-tapes the following is presented. Worker 20's actions were recorded as : 8C2;1.67:Br7/9;4.67 and worker 34 was recorded as C/4/5/4/3(!);1.33 and 4C4;1.42.

3.1.1 *Summary of Results* In all data dossiers on the 57 workers were developed. This comprises a formidable data base and has yet to be completely analysed.

3.2 *Subjective Results*

In addition to the overt/objective form of result each subject compiled an introspective version of his performance. This recorded some of the things he believed passed through his mind at the time of task execution, and any particular factors considered then. Some typical subjective remarks are given in Appendix B.

4. *ANALYSIS OF RESULTS*

The objective and subjective data gathered in the process of carrying out this experiment was very considerable and cannot be presented here in detail. However, some of the interesting features derived from an analysis of the results can be presented in brief.

4.1 *Strategies Employed*

In terms of the technological options utilised the results can be summarised as in figure 4.

	Haul Distance (metres)			
	d = 5		d = 10	
x/d	% Carry	% Barrow	% Carry	% Barrow
0	22	78	0	100
1	50	50	20	80
2	70	30	40	60
3	33	67	33	67
4	40	60	70	30

Figure 4. Summary of strategies employed by groups

4.2 *Tactics Employed*

Within the broad technological options of "barrow" and "carry", a considerable number of techniques, sub-methods or tactical measures were employed. For example:

i. Nine variations of carrying were observed.

C16 i.e. 16 trips of 1 sack per trip.

C9 i.e. 9 trips of 1,7 of 2,1.

C8 i.e.8 trips of 2 sacks per trip (most common).

C7 i.e. 7 trips of 6 of 2, 1 of 4.

C6 i.e. 6 trips 2 of 2 then 4 of 3 (2 & 1 per hand).

C5 i.e. 5 trips of 2,3 of 4(2 per hand), 2.

C4(a) i.e. 4 trips of 4 sacks per trip.

C4(b) i.e. 4 trips of 2,2 of 5, 1 of 4.

C4(c) i.e. 4 trips of 4 sacks/trip but taken in 2X 5metre hauls to make 10m.

ii. Twenty two variations of barrowing were observed (by a factor of 2 depending on whether the barrow was returned to its original position -a deliberate ambiguity in the original instructions). i.e.

B4 = 4 trips with 4 sacks per load.

B3 = 3 trips with one of (6,6,4: 6,5,5; 5,6,5; 5,5,6; 4,6,6; 4,4,8)

B2 = 2 trips with one of (8,8; 7,9; 6,10)

B1 = 1 trip with 16.

iii. Many individuals changed their broad strategies between the 5 metre and the 10 metre haul.

x/d	Carry(5)/Carry(10)	Carry(5)/Barrow(10)	Barrow(5)/Barrow(10)	Barrow(5)/Carry(10)
0	0	2	7	0
1	2	3	5	0
2	4	3	3	0
3	2	1	5	1
4	3	1	2	4
8/4	5	3	1	0

Figure 5. Table showing between trial strategy changes

4.3 *Non-Contributory Work*

In addition to actions that directly contributed to the end result a significant number of actions were recorded that were not directly contributory i.e. had no directly "useful" function. Thus the workers did such things as lift and lower groups of sacks, look around or backwards, walk unloaded to the destination and back. These activities are presumed to have been carried out for information gathering reasons, for problems of checking and for memory reasons.

4.4 *Commentary*

A great diversity of behaviours arose in response to this apparently simple task. Each person solved the problem in strategically similar fashions but with sub- methods that were peculiar to each individual. There was no simple pattern in the data recorded that would enable one to predict behaviour in the given situation but some general trends were evident. However a number of specific points emerged from the experiment which are notable.

- Since a number of individuals made no attempt to ascertain the weight of an individual sack before committing to a barrowing alternative the rationality assumption must be considered suspect. Clearly some people operate partially by habit and analogy whilst others may supply assumed data or default data for pertinent job parameters. Behaviour may only be quasi-rational or may be guided largely by heuristics rather than detailed situation by situation calculations.

- The bulk of people very clearly set about determining the weight of a sack before determining their action strategies. Individuals carried out trial lifts of the sacks, often in various combinations.

- It was evident that human strength and stature were considerations in the methods selected. People of short stature have difficulty handling a fully laden builders wheelbarrow which is implicitly built for tall people as the handles are at a fixed height for presumed full arm extension. Muscular workers were also able to carry two sacks in one hand whilst weaker workers could only carry one.

- The different workers also to some extent solved different problems i.e different individuals "projected" onto the set task various interpretations and constraints that were not explicit in the written instructions. Sometimes this grossly affected the method selected. Thus some workers assumed the articles to be moved were fragile and must be handled with care whilst others did not. Other assumed that the stack patterns must be identical whilst others assumed the stack pattern was all that mattered and which article lay where within this pattern was immaterial.

- The subjects varied considerably in their attitudes to physical work. Some members clearly enjoyed the exercise of physical strength. Others clearly disliked physical effort.

- Workers often changed strategies and tactics as they went along. For example as they discovered that the article was not as fragile as they had assumed or as they got fatigued. Apparently courses of action were not determined as a single-shot process but were varied as new information became available or as assumptions were modified.

5. *INTERPRETING AND EXPLAINING BEHAVIOUR*

5.1 *Intellectual constructs and presumptions*

Whilst it is accepted in good science that one should not project one's preconceptions on behaviour or data, it is nevertheless extremely difficult to make any "sense" of the overt behaviour observed without presuming the existence of reasoning processes. For example, in this exercise, a large number of people took time out to "weigh" the sacks. How might one "explain" this behaviour except insofar as it was an action "designed" to collect a specific piece of "data" pertinent to the problem at hand? Why would such a piece of data be necessary if it were not desired for use in some cognitive or computational process? Similarly people looked around, scanned the environment and presumably gauged distances They tended to ask questions of the person running the test. Here again the presumed purpose is to gather information with a presumed ulterior goal of cognition. Generally, It is hard (if not impossible) to explain purposeful human action of the type displayed here without the presumption of the operation of intellectual processes such as cognition, information processing and reasoning.

5.2 *Major processes in evidence*

It is believed that four distinctive processes are in evidence in the actions of construction workers.

- Information gathering and analysis processes.
- Intellectual activity concerned primarily with problem solving, reasoning and design.

Intellectual processes concerned primarily with physical process control and management.

- Physical action processes related to the use of effector systems.

5.3 *Interpretive frameworks and process insights*

Various interpretive frameworks and models of human thought and action have been proposed by various people to "describe" and to "explain" human action. These may be overlain over the current construction operations in such a way that insights into the operating processes are apparent. Each overlay is a paradigm or way of perceiving and structuring reality with the concepts employed acting as a "language" to describe the process.

A considerable variety of ways of perceiving and construing physico/intellectual activity have been utilised by the authors to perceive structure in the activities of the construction workers. These include:

- Newell and Simons Theory of Human problem solving (Ref 1).
- Bellman and Kalaba's theory of processes (Ref 2)
- Bellman's theory of Dynamic programming (Ref 3)
- Ashby's theory of Cybernetics (Ref 4)
- Salvendy and Seymour's theory of industrial skills (Ref 5)
- H. Simon's theories of decision premises and decision making. (Ref 6)
- O'Briens theory of knowledge bases (Ref 7)

This list is virtually endless with each conceptual framework highlighting a particular facet of the observed process. A summary of mental models and other points of view relevant to this study is given by Johnson-Laird in reference 8. The upshot of applying these conceptual overalays is to perceive this test task to involve a host of complex, interwoven and hierarchically structured processes which defy simple description or analysis. Possible this endeavour is beyond the current state of the art.

6. *AN EXPLANATORY THEORY*

Notwithstanding the complexities remarked on above the authors believe they have been able to gain some broad understanding of what is going on in the solution of a small construction task such as this. The following "word picture" is presented not to outline the theory in detail, which is not possible within the confines of this paper, but rather just to give a "flavour" of what is involved.

The first stage involves developing an internal (symbolic representation) of the "problem space". This involves two substages. One is a development of the general physical context of the problem. The other is a representation of the problem as the desired state to achieve. Since in this instance an internal model of the physical environment representing the current physical state of the problem system is desired, the worker must "map" the environment and determine the geographic constraints etc etc. In this instance the process is largely carried out by a process of remote sensing with the eyes. But additionally by a small test routine involving the weighing of the target object. Finally, enquiries may be made as to the constraints or restraints that may apply on the solutions space. This may require a set of overt actions or interactions with the environment. Next an objective function, such as minimise personal costs, is developed.

A combination of all the above finally defines the problem. Now by referring this definition to a data base which will include any prior experience in relation to this type of problem space a set of valid operators and their characteristics is developed. Thence by processes of reasoning and logic a set of valid technological processes by which the goal state can hopefully be achieved is developed. Generally this will involve a process of dynamic imagery and mental simulation of the technological process involved. Prediction models are used extensively at this stage. During this simulation actual physical and mental costs are determined and then value against an internal value structure.

Having developed a set of actions that can yield the end result and having calculated on the basis of personal utility functions the personal cost, one strategy is chosen for execution.

Now the individual will begin to act. His brain will now have a complete plan for solving the problem, albeit in an encoded form, which can be used as the basis for programming his physical effector systems. The programming of the physical effectors involves considerable mental activity and involves many sub-processes such as control, calculation, testing and checking.

The execution of every act transforms the target system from one physical state to a new state which is updated as the current state. Continuous monitoring of the physical environment is needed to define the current state and compare it to the desired or gaol state. The brain gets a continuous flow of data updating the current state and providing updates of the costs of the technological processes involved. New predictor models as to the costs of completion of the job using the current processes are continually developed. If the current method drops in ranking , in terms of the objective function, as compared to perceived technological alternatives then a switch in method may be made. If the value framework were to change during the exercise, say due to fatigue, the method may again be changed. When the current state equals the goal state the operation stops and the process is complete.

7. *A PREDICTIVE THEORY*

In a similar way to the explanatory model a model can be developed to predict the actions and choices that will be employed by a particular worker to solve his problem. The rudiments of such a theory have been developed by the present authors but again the specific format is both too tentative and too complex to outline in this paper. The concept however is that by inputting the characteristics of the task, the worker and his utility functions and by application of a very complex algorithm a model of likely action may be developed.

8. *IMPLICATIONS OF THIS WORK*

Even though studies of the kind developed in this paper are still in their infancy and lack full sophistication there are many implications of this work for people trying to develop machines to replace humans in certain tasks and for people who seek to improve worker skill and productivity. Firstly people in the robotics field should note the role of and the sophistication of the real time sensing and analysis systems that provide the human with data during field operations. For those in the AI field it should be noted that to give a machine problem solving capabilities it will be necessary to develop "computer" "languages adapted to action design and control. In terms of data bases required for machine operation extensive "knowledge" in the form of predictor models and state determined system behaviour will have to be incorporated. Additionally the nature, role and function of tools will need to be incorporated. For those interested in productivity the implications of this type of study are immense. This work shows that in this "trivial" task the performance differentials between individuals is extremely large. It further clearly indicates the potential for major pay-offs that should result from the training of,

and from increasing the cognitive sophistication of, construction workers. If a task such as this is considered a "primitive" of all construction work and is multiplied millions of times during the life of a project then the implications for productivity can be perceived.

9. *CONCLUSIONS*

To many people in the construction sector the work of construction labour is perceived as basically brute physical. Mental content and contribution is minimal. If work is difficult it is due to the complexity of the environment or task and not to any feature of the worker.

This paper concludes virtually the opposite. All the complexity lies in the worker and little relatively in the environment or task. The field work presented here aims to attest to this position and formalise the fact that even in elemental construction cognitive and behavioural complexities are great.

The general conclusion of this work however is not negative. It is believed that whilst the cognitive and physical processes at work are very complex they are potentially understandable with effort. This understanding should go a long way to realising the possibility of significant automation in the construction arena in the near future.

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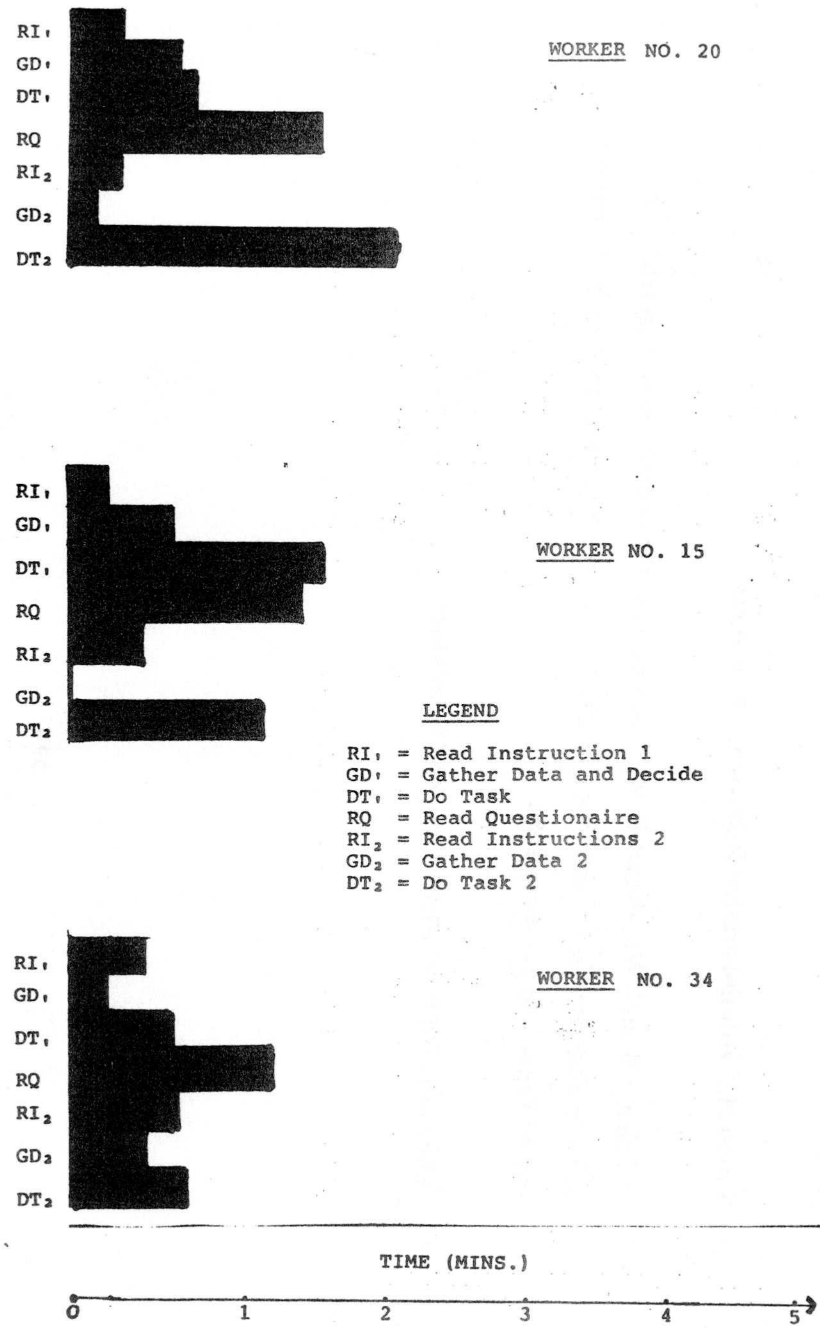
APPENDIX A

CONSOLIDATED ACTION CHART



APPENDIX A

MATERIALS HANDLING TASK: EXPERIMENTAL DATA

Student No.: Record: M,V X/D = 4

Date: 22/10/86 Location: L5 Material Type: B

Time	Action	Comment
0'00"	Reading T1	B=0, M=20, C=25
0'10"	Glances at cone.	This action has been observed several times in others. (But not always recorded or seen).
0'45"	Tests weight of nearest item.	10-15 secs. spent folding and pocketing T1.
0'55"	Tests two more items for weight.	Looks at barrow on 2 occasions.
1'05"	Picks up 2 in right hand and confirms (?) wieght is comfortable by jiggling up and down then bends and picks up 2 more items in left hand.	
1'25"	Back at M, initially puts 2 to right hand then adds a third and tests at 1'35" then bends and adds 2 to left hand.	Pauses to count or check remainder and when starts walking does not look particularly well balanced.
2'00"	Picks up 2 per hand and carries.	
2'25"	Picks up 2 in left hand and 1 right hand and carries.	
2'30"	Completes transfer.	Gets T1 and rereads, has stacked material approx. 1m beyond cone.
5'10"	Reading T2.	B=65, M=25, C=15.

General Observations:

APPENDIX B - SUBJECTIVE REMARKS

Typical Comments

* In the first execution the alternative methods I thought of were:- 3 methods

  (i) Using the wheelbarrow to transfer the materials.

  (ii) Physically moving the materials myself - two at a time.

  (iii) Physically moving the materials myself - as many as I can carry.

* The method adopted by me, was not an obvious one. It was the method I thought was quickest and least demanding.

* In the first execution, I decided to opt for moving the materials myself, two at a time because the transfer distance was a short one. It would be a waste of energy and effort to drag a wheelbarrow 5m when you can just as easily walk 5m.

  In the second execution, I felt the transfer distance was too far (10cm) and opted for the wheelbarrow. Completing the task in two trips.

* ...Anyway in the first task, the first solution that entered my mind was to use the wheelbarrow (because it was lying there). I opted not to use it because by the time the barrow was full, I would have moved half of the cylinders already. I proceeded by picking up 2 cylinders at a time.... In the second case I decided to use the wheelbarrow because the transfer distance was too far. I completed the task in two trips.

* My next step was to randomly pick up a few of the items and feel if they were all of constant weight. If they were not, I would have moved the lighter ones by hand thus avoiding taking up unnecessary space in the wheelbarrow as they visibly were all of uniform shape and size.

* Although it was thought that manually handling the items may have been quicker, more effort would have been expended and I decided for the purposes of this exercise I could forego a little more of my valuable time and reduce the overall effort.

APPENDIX C

INSTRUCTIONS FOR MATERIALS HANDLING TASK

TASK: Transfer the stockpiled items from their present position adjacent to a road marker cone (witches hat) to a corresponding position adjacent to another marker cone 5m away.

CONSTRAINTS:

(1) Any method may be used, but consider the material a building product that should not be thrown, dumped, dropped or dragged.

(2) The arrangement of items at the second cone is to be essentially the same as the original stockpile.

(3) Successful completion of the task is the only requirement. No other performance measures are being adopted.

TASK: Transfer the stockpiled items from their present position adjacent to a road marker cone (witches hat) to a corresponding position adjacent to another marker cone 10m away.

CONSTRAINTS:

(1) Any method may be used, but consider the material a building product that should not be thrown, dumped, dropped or dragged.

(2) The arrangement of items at the second cone is to be essentially the same as the original stockpile.

(3) Successful completion of the task is the only requirement. No other performance measures are being adopted.

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