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1. Introduction

Over the last decades, the work situation of the operator in the chemical and petrochemical process industry has undergone significant changes (Kragt, 1983). First of all, with the development of pneumatic control instruments, there was the transition from local manual control to local automatic control. With the introduction of pneumatic and electrical signal transformers, the central control room came into being, which during the sixties housed the first digital computers, at this time only used for data logging. During the eighties in most companies a transition has been taking place from panel instrumentation to distributed instrumentation and computerised operating systems. This development has resulted in different requiremens being placed on the operator. Indeed, as a result of the increase in scale, the integration of processes and the increasing complexity of most processes, higher requirements are set with regard to the task carried out by the operator.

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The operator in the central control room is part of a man/machine system. Kragt & Daniëls (1984) distinguish two approaches in the design of man/machine systems:

1. the ergonomic approach: based on the operator, fitting the "machine" (interface, work situation) to the capabilities and limitations of human beings;
2. the selection and training approach: based on the "machine" finding the most suitable person (selection) and increasing the level of suitability by training.

It almost goes without saying that in an ideal situation attention is paid to both approaches.

In recent years more and more signs from industry have indicated that, in addition to the ergonomic approach, the selection and training of process operators also required more attention. In 1986 a workshop was organised within this framework under the motto: "The skills of the process operator, an unknown area in the field of process automation". Among those taking part were 11 Dutch chemical and petrochemical companies (Bollen & Meerbach, 1986). One of the most important conclusions of this workshop was that both training and selection of process operators must be adapted to the changing tasks.

According to the various companies taking part, the selection criteria used until now no longer gave sufficient guarantee of a correct choice. Jetten (1987) also draws attention to the lack of an objective selection method and the poor coordination between external and internal training as the main problem areas with regard to selection, education and training of process operators.

In the present study the problem of selecting and training process operators is studied in greater detail using the "work sample approach". Simulation techniques are used to develop work samples.

2. Work samples and selection

The first stage in the development of a selection instrument is to carry out a task analysis. The aim of a task analysis is to identify those characteristics (behaviour and ability requirements) which are necessary for a person to carry out a task well. Moreover, these characteristics must be suitable as predictors for how a person will carry out the tasks in the future (Algera & Greuter, 1989).

In the literature two approaches are identified: the sign approach and the sample approach (Wernimont & Campbell, 1968). In the sign approach the reality is represented by an abstract symbolic system, in which the symbols refer to theoretical concepts. Predictions are based on performance theories. As the work behaviour and individual characteristics are linked together by hypotheses, these characteristics are regarded as predictors (signs) of future work behaviour. In the sample approach the predictions are based on a one-to-one correspondence: consistency between test and work behaviour. The behavioural consistency approach (Schmitt & Ostroff, 1986) is explicitly based on consistency between the relevant dimensions of the real task behaviour and the samples which are used in the selection to simulate the task.

According to Roe (1982), the following steps must be taken in developing a work sample:

1. initially a start is made with an inventory of the tasks of a given function;
2. a representative sample is taken from this;
3. candidates carry out the tasks in this sample;
4. and finally the performance is used to predict the performance in the function as a whole later on.

Asher & Sciarrino (1974) identify two kinds of work samples: motor and verbal. The motor work sample corresponds with what Robertson & Kandola (1986) call the psychomotor work sample. Here this involves tasks such as typing, sewing, using a tool, etc. In addition to the psychomotor work sample, Robertson & Kandola also identify three other types of work sample: i.e. individual, situational decising making (e.g. in-basket tests), job-related information (e.g. usually paper and pencil knowledge tests which examine the amount of information a person holds about a particular job) and group discussions/decision making (e.g. two or more people being put together to discuss a particular topic and their performance in the discussion is evaluated).

As early as the twenties and thirties work sample tests were frequently used in test programmes in Europe to recruit soldiers. However, the sign approach has been the most frequently used method in the development of selection tests over the last few decades, although during the last fifteen to twenty years, the sample approach has become popular once more. In fact, the literature (Asher & Sciarrino, 1974; Robertson & Kandola, 1982) shows that work samples as a selection tool are better predictors than the more conventional tests, such as intelligence, personality or aptitude tests. Although work sample tests were frequently used during the twenties and thirties, we find only one example of a work sample test used for selection purposes in a chemical factory. Hiscock (1938) describes a set of selection tests for process operators in a paint factory. One of these was a test, in which the candidate had to carry out five different tasks in different parts of the test room "at the same time". This was a situation which was similar in many respects to the task situation, where the process operator was responsible for various different processes which each had to run at the right temperature and pressure and where the right amount of the right substances had to be added at the right moment.

According to Cook (1988), the more traditional work sample tests are developed for motor tasks, and not so much for activities which are very varied and where the work is carried out more with people than with things. The traditional work sample test is in fact mainly a (manual) skills test. For jobs which do not involve motor skills and which are more in the management sphere, in-basket tests and group discussions are used. In the more traditional work sample tests until now relatively little attention has been paid to cognitive aspects. And although traditionally the job of the operator involved considerable motor skills, as a result of automation and an increase in scale, among other things, the emphasis has come to lie more and more on cognitive abilities.

3. Work samples and training

With regard to operator training, we can identify three types of training in the process industry:

a. basic training, which involves the learning of basic process knowledge and general operator skills;
b. specialised training, in which skills are learnt which are necessary to control a specific process;
c. refreshment training, a course for experienced operators to prevent loss of knowledge and skills.

These three types of training are arranged according to the level of increasing specificity. They can also be arranged according to time. First of all, operators should be given a basic training in which they learn general principles of the operator's job. Only then they can learn how to control a specific process. This then takes place in specialised training. Once an operator is experienced, it is found that in practice a number of situations only occur sporadically (e.g. during the startup of a factory, or as a result of the increasing automation). However, refreshment training is needed in order to have all the necessary knowledge at hand and to be able to apply it directly and purposefully.

In the selection of personnel the work sample approach emphasises the development of a test instrument, consisting of one or more tasks which represent the fundamental skills with regard to a certain function. A great deal of the study on work samples has been carried out with those people who already have the skills needed for specific activities. The work sample test thus acts as a selection instrument that has to identify the most suitable (= most experienced or best trained) candidate. Differentiation takes place on the basis of simulated work behaviour.

However, if someone still does not have the skills required to carry out the activities, the trainability testing approach can be used. Trainability tests are in fact a subtype of a work sample which indicate how well/quickly a candidate can *learn* the new skills (Cook, 1988). Robertson & Downs (1979) also call trainability testing a special form of work sample testing. It involves a structured and controlled learning period with a work sample in which the "how" and "why" of what is done is systematically observed. Trainability tests can be used as a pass/fail selection instrument for acceptance on training programmes.

For years the prediction of trainability has been an important research area. From the point of view of saving costs, it is indeed very attractive if it is possible to identify in advance those people who perform best during training, who complete training the quickest or can skip parts of training. Gordon & Cohen (1973) assign the lack of success in this research area to the fact that (paper and pencil) psychological tests have mainly been used as predictors. They studied a training programme for welders, consisting of eleven different parts/tasks (with increasing degree of difficulty). The most significant conclusion was that the performance on the initial tasks was found to be an excellent predictor of the final performance. Gordon & Cohen used the time needed to learn the tasks as the criterion for performance. The more tasks included in the predictor (up to a certain level), the more accurate was the prediction. Thus, there was still a considerable difference between the correlation of the time of task 1 with the total time (.69) and the correlation of the time of task 1+2 with the total time (.79).

Although the results of Gordon & Cohen's study show that performance at the start of a training can be a good predictor of the end result, we must still be very careful when generalising these results. The various tasks in the training programme for welders have in fact shown that they are very similar. The question now is, whether initial training performance is also a valid predictor of trainability if a training programme consists of more diverse tasks. In the development of trainability tests we also see that emphasis is placed on psychomotor skills, as is the case with work sample tests. In their review of trainability tests Robertson & Downs (1979) name, for example, activities such as carpentry, welding, sewing, bricklaying, fork-lift truck and dental activities, but put forward the possibility of using trainability tests in a wider professional area, with less emphasis on typical manual skills. However, they indicate that whenever trainability tests are applied, three important points must be taken into consideration:

a. the contents of the work sample (the task to be learnt);

b. the learning method;

c. the general environment in which the learning takes place.

When developing trainability tests, a one-to-one correspondence should be aimed for in all three areas.

In the United States we find the "miniature job training and evaluation approach" (Siegel & Bergman, 1975; Siegel, 1983) which bears some similarity to the trainability testing approach in England. The miniature job training and evaluation approach is based on the notion that if someone shows that he can learn and do well in a job sample, this is also true for the job as a whole, provided that he is given the correct on-the-job training. Those in favour of this approach emphasize in particular, in addition to the relatively high content and predictive validity, the fact that this is a "fair" selection method, whereby the "underpriviledged" and unskilled are also given a fair chance. In recent years in the United States it has become very important that a selection method can be defended in court. The "Equal Employment Opportunity" legislation prefers tests which are as similar as possible to the activities in question. As in addition to a high face validity work samples generally also have a high content validity, many legal problems can be prevented (Cook, 1988). Research by Cascio & Philips (1979) supports the notion that work samples are in fact "more fair" than the conventional paper and pencil (aptitude) tests. Relatively speaking the same number of coloured people, Latin American and white people achieved good performances in the work samples they used (mainly motor).

4. Training simulators and validity

If we want to use a simulator for training, then it soon becomes clear that the type of training determines which type of simulator is most suitable. Bruens, Oxenaar & Steinbuch (1987) identify roughly four types of simulators:

a. basic simulators: simple simulators which simulate the basic principles of a process or power station;
b. generic simulators: general simulators which simulate a type of process or a type of power station with a reasonable degree of detail;
c. replica simulators: simulators which simulate a specific installation or power station, in which both the operation and the behaviour do not differ from the real installation or power station;
d. function simulator (part task simulators) which simulate an isolated part of an installation.

Replica or function simulators seem to be the most suitable both for specialised and refreshment training. A one-to-one simulation with regard to (a part of) a specific process is needed then. On the other hand, a basic or generic simulator is more suitable for basic training. However, the differences between the simulators are in no way absolute. The various simulators can be placed on a scale showing how close they are to reality. Here we come to the question of the validity of simulators.

Too frequently still the validity of a simulator is compared to the degree of similarity with the simulated system. When developing training simulators, the objective of high fidelity is frequently only reasoned in terms of face validity or acceptance by users and not in terms of set training objectives (Stammers, 1981). Moraal (1983) states that the validity of simulators is determined by three components:

a. face validity: experienced users or experts think that the simulator "looks" or "feels" realistic;
b. functional similarity: the simulator behaves in accordance with certain expectations (here functional similarity is defined by taking into account the man/machine system);
c. physical similarity: the degree of similarity in terms of the hardware/physical components of the simulated system.

In addition, Moraal states that the validity of a simulator depends on the purpose for which the simulator is used. Thus, for example, the functional similarity of a training simulator is high if the learning transfer is large, in other words, if after the simulator training a shorter training period is needed on the system itself. On the other hand, the functional similarity of a research simulator is high if the experimental results with a simulator correspond with those from experiments with the simulated system itself. In addition, we can say that the validity of a simulator which is used as a selection instrument is mainly determined by its predictive power. In other words is the performance on a simulator indicative for the (later) performance in the work situation?

5. The development of work samples for process operators

As we already noted in section 2, the carrying out of a task analysis is essential both for the development of a selection instrument and a training instrument. Indeed, the aim of a task analysis is to identify those characteristics (behaviour and ability requirements) which are needed to carry out a task well. When we talk about carrying out a task, what do we really mean in the case of process operators?

The work of operators in the chemical process industry consists of various tasks. The activities take place partly "inside" (in the central control room) and partly "outside" (in the factory amongst the equipment). In this study we focus on the tasks of a control room operator who must control the processes from his central position behind a panel or console using a distributed instrumentation system. On the basis of a case study in a chemical batch factory, Piso & Kragt (1980) identify among other things the following activities: control, observation, telecommunication, consultation, administration and personal care. Wickens (1984) identifies the following two tasks as the most important:

a. control;
b. fault diagosis.

Initially, we will concentrate on the control task of a process operator.

The use of a simulated process in developing work samples seems to be a suitable method to approach both the selection and the training problem. The sample approach is selected for three reasons. First, it is a good way of obtaining information on the critical operator skills. Currently the operator function is characterised by the lack of well-defined performance criteria (Kragt, 1983). By means of simulation and the construction of work samples, a more detailed observation of relevant performance criteria is possible and more information can be obtained on the critical operator skills. Second, the development of these skills can be studied in future research, using work samples as a training instrument. Third, literature indicates that work samples as a selection tool are better predictors than the more conventional tests (Asher & Sciarrino, 1974; Robertson & Kandola, 1982).

As industry has to a large extent switched over from panel instrumentation to distributed instrumentation or intends to do so in the near future, we are developing work samples on a process simulator to which several VDU's can be linked. A work sample is not just a simulated process part, but also contains the corresponding control commands and the control actions of the operator. The word "work sample" is used to mean a representation of (a part of) the work behaviour required to control a process well.

6. Identification of control problems

In conducting an analysis of the control task of the process operator, we used a content-oriented strategy (Society for Industrial and Organizational Psychology Inc., 1987). Both van Meurs (1986) en Geurts (1987, 1988) gave the first impuls to identifying some of these general control problems.

Since detailed task information is necessary for simulation in a work sample approach, we used different techniques to gather this information, e.g. observation, interviews and questionnaires. The observations were carried out in the form of participating observations, mostly in the central contol room during operator shifts. Approximately 30 semi-structured interviews were also held with operators, instructors and production managers during four weeks at six different companies from (petro)chemical industry. First, by using the critical incidents method (Flanagan, 1943), an attempt was made to specify as many situations as possible in which inexperienced operators had difficulties in carrying out their control task. Then, the critical components and factors which we named "control problems" were derived from these concrete situations. Finally, a questionnaire was developed, which contained these control problems, divided into three categories (Ridderbos, 1988):

a. process-linked control problems;

b. external control problems;

c. task related control problems.

In this section the most important results of this questionnaire are also discussed briefly, in so far as they involve the inclusion of the control problems in a work sample. A list of the control problems included in the questionnaire is given in table 1.

	Occurrence (in %)		Content Validity Ratio	
	Operators	Engineers	Operators	Engineers
I Process-linked control problems				
series connection	100	100	0,89	0,69
recycling	100	100	0,56	0,69
time delay	100	92	0,78	0,67
parallel connection	100	85	0,78	0,45
time constant	94	100	0,76	0,23
hysteresis	94	77	0,41	-0,20
asymmetry	61	85	0,64	0,45
inverse response	56	31	0,20	-0,50
II External control problems				
change in specification of raw material	100	85	0,67	0,09
atmospheric influences	94	77	0,29	0,20
chance in specifications of product	78	85	0,43	0,09
III Task related control problems				
abundance of alarms	100	100	0,67	0,54
fault diagnosis	100	100	0,89	0,54
choice of setpoint	100	92	0,67	0,17
inaccurate information	100	85	0,56	0,09
conflicting information	89	77	0,13	0,20

Table 1.
Overview of control problems, their assessed occurrence by operators and control engineers in various processes and the Content Validity Ratio.

Respondents were experienced operators and control engineers from six different companies from the (petro)chemical industry. In each company the questionnaire was completed by 3 experienced operators (total: 18 operators) and - depending on availability - between 1 to 3 experienced control engineers (total: 14 engineers). Respondents were asked for each control problem e.g. whether it occured in "their own" process and whether it should be included in a work sample. Table 1 gives a summary of the results to these two questions. It appears that only the control problems "asymmetry" and "inverse response" are indicated by less than 75% of the operators as present in "their own" process. For the control engineers this is the case only for "inverse response".

The judgements about the inclusion of a control problem in a work sample are summarized using Lawshe's (1975) content validity ratio:

$$CVR = [n_e - (N/2)]/(N/2)$$

where N equals the number of respondents indicating the occurrence of the controlproblem in "their own" process and n_e is the number of respondents indicating the necessity of the inclusion of the control problem in a work sample. A summary of these judgements is contained in table 1. Note that 1.00 in this table indicates unanimous agreement on the part of the respondents that a control problem should be included in a work sample; -1.00 indicates unanimous agreement that this was not necessary. This table shows that the operator CVR has a positive value for each control problem and is actually quite high for most control problems. Although the engineer CVR is lower for almost every control problem, it only reaches negative values for "hysteresis" and "inverse response".

To find a ranking for the process-linked control problems on the dimensions "frequency" and "difficulty" the technique of paired comparisons was used. Table 2 shows the ranks, which were established for the process-linked control problems for each dimension and for each group of respondents.To find the degree of agreement among the sets of ranks within each group of respondents, Kendall's coefficient of concordance, W, which ranges in value from 0 to 1.0 was calculated. If the ranks assigned by each respondent to the eight process-linked control problems are the same as those assigned by every other respondent, then W = 1.0. If there is maximum disagreement among the respondents, then W = 0. We also tested this coefficient of concordance for significance. The results are summarized in table 3. This table also contains the average rank correlation coefficient (r') and the reliability coefficient (r_{tt}) (Edwards, 1967). r' is the average of the rank correlation coefficients for each pair of respondents and ranges from -1.0 to +1.0. r_{tt} gives an impression of the reliablity of the rankorder we found and ranges form 0 to 1.0. This reliability coefficient reflects the correlation between our group of respondents and another comparable group of respondents, who would also rank the eight process-linked control problems.

Frequency		Difficulty	
Operators (n=17)	Engineers (n=14)	Operators (n=15)	Engineers (n=14)
1. series connection	series connection	series connection	time delay
2. time constant	recycling	time delay	series connection
3. time delay	time constant	time constant	recycling
4. recycling	time delay	parallel connection	time constant
5. parallel connection	parallel connection	recycling	parallel connection
6. hysteresis	asymmetry	hysteresis	asymmetry
7. asymmetry	hysteresis	inverse response	hysteresis
8. inverse response	inverse respone	asymmetry	inverse response

<u>Table 2.</u>
Ranking of process-linked control problems by operators and control engineers on the dimensions "frequency" and "difficulty".

Table 3 indicates that the rankings of the process-linked control problems show a significant degree of agreement. However, a closer inspection of our data reveals that a cluster of three control problems, which rank lowest on both dimensions, is responsible for this finding. This cluster consists of "hysteresis", "asymmetry" and "inverse response". These are the control problems which, according to our respondents, do not always occur in every type of chemical process. They constitute the missing data in the datamatrices, which are generated from the paired comparisons. Therefore, a corrected coefficient of concordance (W') is calculated for the rankings of the remaining control problems and tested for significance.Table 3 summarizes that both groups of respondents still show a significant degree of agreement in the ranking of the process-linked control problems on the "frequency" dimension, while neither group of respondents shows a significant greater degree of agreement on the "difficulty" dimension then would be expected on the basis of chance.

There may be a number of reasons why the respondents do not agree in their rankings on the "difficulty" dimension. It may be because "difficulty" has been ambiguously interpreted by the respondents. Or it may be because the control problems do not differ sufficiently in degree of difficulty. If the differences in difficulty among the control problems are so small that they can not be reliably discriminated, then we can not expect respondents to agree in their ranking of the control problems on this dimension.

Respondents/ Dimensions	Agreement in ranking of all eight process-linked control problems			Agreement in ranking of process-linked control problems without a, i & h*		
	W	r'	r_{tt}	W'	r'	r_{tt}
Operators/frequency (n=17)	0,34 p< .01	0,30	0,88	0,35 p< .01	0,31	0,88
Operators/difficulty (n = 15)	0,25 p< .01	0,20	0,79	0 n.s.		
Engineers/frequency (n = 14)	0,65 p< .01	0,62	0,96	0,23 p< .01	0,17	0,74
Engineers/difficulty (n = 14)	0,20 p< .01	0,14	0,69	0,23 n.s.		

Table 3.
Agreement in ranking among respondents on the dimensions "frequency" and "difficulty" for all eight process-linked control problems and for the control problems* without "asymmetry", "inverse response" and "hysteresis".

In this section we will not discuss the other results of the questionnaire in greater detail, but end with the conclusion that in view of the above presented results we decided to include in a work sample the following five process-linked control problems:

1. series connection;
2. time delay;
3. time constant;
4. recycling;
5. parallel connection.

The simulated process, which is used to construct a work sample, will have to contain at least these process-linked control problems. The task related and external control problems will have to be included in a work sample either by implementing disturbances in the simulated process itself or by varying instructions in the experimental task situation.

7. Some concluding remarks

By means of a simulated process (Geurts, 1989) and in view of the results of the observations, interviews and questionnaire, we have developed some basic modules, which are a starting point in the development of work samples for both a selection instrument and a training instrument for basic process control skills. Our basic modules, which each contain at least one process-linked control problem offer the following possibilities:

a. the degree of difficulty of a basic module can be varied e.g. by varying the difficulty of the process-linked control problem in that module or by introducing task related or external control problems;
b. the control problems can be combined by connecting the basic modules, so that interactions between process components can be simulated.

This offers enormous possibilities to compose a lot of process situations, differing in difficulty and complexity. The next step is to define performance criteria. Many questions still have to be answered. One of these questions is how to define performance criteria: unidimensional, multidimensional? This simulation offers possibilities to look in much more detail at operator behaviour than is possible in practice, because much more control behaviour can be measured. The above shows that we have embarked on a clear course with the work sample approach. Although we have still only taken a few steps in this direction, we believe that it will ultimately prove to be worthwhile.

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