Competence assessment is also required if workers are assigned to new areas of work. In the offshore industry, considerable importance is being attached to the issue of demonstrating competence, following the recommendations of the inquiry that followed the Piper Alpha disaster.

- **Validation of training effectiveness.** The effectiveness of the training system in terms of its capability to equip people with the skills necessary to carry out a job safely and efficiently, can only be determined by long term feedback from operations. The types of feedback that are important in evaluating a training program include incident reports, which should explicitly identify the role of lack of knowledge and skills in accidents, and reports from line managers and supervisors.
- **Definition of skill maintenance training.** All skills decline with time and it is therefore important to specify the needs for skill maintenance training by means of refresher courses or other methods.

3.6. OPERATOR CHARACTERISTICS

This group of PIFs concerns the operator characteristics of personnel such as operating experience, personality, physical condition and age. Considerable emphasis is placed on individual differences by many managers. There is a strong belief that all problems can be solved by better motivation or more intrinsically capable people. However, although many of the individual factors discussed in this section might reasonably be expected to have an effect on human error, in practice there are few controlled studies that have actually established such a link. Nevertheless, it is important that engineers are aware of the wide range of factors that could impact on error.

3.6.1. Experience

Although training can provide workers with adequate practice in process control, some elements of expertise develop primarily with operational experience. The degree of skill and experience with stressful process events are two separate PIFs which will be discussed thoroughly in this section.

3.6.1.1. Degree of Skill

The amount of the "on-the-plant" experience of personnel determines the extent that well-known knowledge can be applied to real-life problems, particularly under time pressure and high workload. Although engineering schools make an effort to provide all the required theoretical knowledge to young graduates and process workers, many people find it difficult to apply such knowledge to the plant, especially in the beginning of their employment period.

As has been discussed in Chapter 2, people go through three stages in the acquisition of skills. An educational course usually gets people to the cognitive or knowledge-based stage, where principles of physics and chemistry are well learned. With further practice, possibly on the plant, people "compile" their knowledge into practical "know-how" in the form of rules which can solve applied problems. The transition to the rule-based stage is analogous to software source code being translated into an executable form of code. After considerable experience people can reach the skill-based stage, which requires the least attentional and memory resources for the performance of a task, as discussed in Chapter 2. It is only at the rule- and skill-based stage that people will be able to apply their theoretical knowledge effectively to real-life problems. The following two examples (Kletz, 1994b), illustrate failures to apply well-known knowledge.

Example 3.8 Failure to Apply Well Known Knowledge (Kletz, 1994b)

Scaffolding was erected around a 225-foot distillation column so that it could be painted. The scaffolding was erected when the column was hot and then everyone was surprised that the scaffolding became distorted when the column cooled down.

Example 3.9. Failure to Realize that Changed Physical Conditions Would Render Safety Systems Ineffective (Kletz, 1994b)

A tank burst when exposed to fire for 90 minutes. During this time the Fire Department had, on advice of the refinery staff, used the available water for cooling surrounding tanks to prevent the fire spreading. The relief valve, it was believed, would prevent the tank bursting. They failed to realize that the tank could burst because the metal could get too hot and lose its strength. Below the liquid level the boiling liquid kept the metal cool, but above the liquid level the metal softened and burst at a pressure below that at which the relief valve would operate.

3.6.1.2. *Experience with Stressful Process Events*

Experience with stressful process events can be obtained both through simulator training and "on-the-job" practice. Both types of practice have their pros and cons. In simulator training, greater control can be exercised over the course of the process transient and the operating team can benefit fully from well designed instructional methods. What can be missing however, is the stress factor arising from potentially disastrous plant consequences. "On-the-job" experience of stressful events can present process workers with many aspects of their work which cannot be represented faithfully in an artificial environment. However, it is questionable whether people can learn effectively under stress and there is little control over any sort of misunderstanding that process workers may develop. It is a combination of "controlled" and "real-life" stressful process events which will benefit the workers.

Studies by Berkun (1964), Abe (1978), and Gertman et al. (1985) have found that people who have coped successfully with many previous stressful experiences perform better under stress than those who have not had these experiences. What is not evident from these studies is the kind of attitudes and skills that experience equips people with in order to perform effectively in future stressful situations. One can postulate that such beneficial experiences may help people develop generic problem solving strategies, remain vigilant to changing system conditions, and continually evaluate their working assumptions. With regard to their work attitudes, they may become more confident that they can cope with the unexpected, and may therefore exert greater emotional control and maintain good working relationships with their colleagues.

3.6.2. Personality Factors

This category includes a number of personality factors which can have an influence of human performance, particularly under stress. Although it is desirable to devise personality assessment tests to select the most suitable individuals for a job, the usefulness of these tests is questionable for CPI operations. A recent review of the state of knowledge of current practices in selecting workers for process control jobs was carried out by Astley et al. (1990). A finding of this study was that the basis of the choice of various psychological tests and selection devices was often superficial. There were rarely any measures of performance that could be used as a basis for deciding on which tests are likely to be valid predictors of performance. This is an important point, because process control tasks may vary considerably from plant to plant according to the different levels of complexity and different control philosophies. It may therefore be inappropriate to use the same general selection procedures in all cases. The methodologies of task analysis which are described in Chapter 4, aim to identify the necessary types of skills for specific process worker tasks and to ensure that test items are matched to the real needs of the workers.

It is worth noting that personnel managers who were interviewed as part of the above study had few expectations that selection would enable them to overcome inadequate training, job, or work design. Selection was seen as something that had to be done completely and conscientiously in order to make the best decisions possible. There was no expectation that, on its own, selection would solve operating problems.

The following section will address six personality traits that may affect human reliability, namely, motivation, risk taking, risk homeostasis, locus of control, emotional control, and type "A" versus type "B" personality.

3.6.2.1. Motivation

Considerable attention has been focused on the kind of motives which drive the decisions and choices of individuals in a work setting. An influential model of motivation was the "scientific management" movement of F. W. Taylor (1911) which viewed motivation largely in terms of rational individual decisions to maximize financial gain. This theory claimed that workers only wanted to make as much as possible for as little effort as possible, and that they were neither interested in, nor capable of planning and decision-making.

Later theories by Maslow (1954) showed the narrowness of that view, and the importance of factors such as social, esteem, achievement, and other needs. Maslow has put forward a hierarchy of five types of needs in descending order of priority:

- *Existence needs:* food, drink, air, sex
- *Security needs:* shelter, secure sources of the existence needs, freedom from fear, need for structure in life
- *Social needs:* affection, belonging to a group
- *Esteem needs:* need to be valued by self and others, competence, independence, recognition
- *Self-actualization needs:* self-fulfillment, achievement

Maslow postulated that the most basic level of need which is not yet satisfied is the one that controls behavior at any moment in time. Hence, people will not be very concerned with pursuing needs for esteem if they are threatened with the loss of their job, and therefore their security. While there is evidence that the first two levels do need to be satisfied in most people, before much concern is shown with the remaining levels, there does not appear to be any clear progression among those higher levels.

Another influential theory of motivation was proposed by Herzberg et al. (1959). This theory postulates only two levels of motivation. Herzberg contrasted wages, working conditions, interpersonal relations and supervisory behavior which he called "hygiene" factors, with recognition, achievement, responsibility, and advancement which he called "motivators."

Although the theories of both Maslow and Herzberg seem to be conceptually simple, they were probably among the first to recognize the role that various "system factors," such as equipment design, procedures, training, organizational culture and so on, play in the motivation of workers. When management has applied sound human factors principles to CPI tasks, training has provided the required skills to cope with all contingencies, and workers are actively involved in their job through participation schemes, then it is likely that motivation will be high.

Recent research on motivation theories has provided more elaborate models of the factors which drive human behavior and has taken into account issues of individual differences and the influence of the social and cultural background of the process workers. More extensive discussion on motivation theories is provided in Warr (1978) and Hale and Glendon (1987).

3.6.2.2. Risk-Taking

The concepts of accident proneness and risk taking as a personal trait predisposing the individual to a relatively high accident rate was first suggested by three statisticians, Greenwood, Woods, and Yule in 1919. They published an account of accidents sustained by workers in a munitions factory during the First World War and showed that a small minority of workers had more accidents than they would have done if chance factors alone were operating. Despite these early findings, attempts to explain them in terms of personality characteristics have met with little success. Either these characteristics explained only a maximum of 20% of the variance in accident rate, or a factor found to be relevant in one case was found to be irrelevant in others. The concept of accident proneness is discussed in detail in Shaw and Sichel (1971) who conclude that there is little statistical evidence for the trait.

Simpson (1988) reviewed studies which considered individual differences in risk perception and the effects of these differences on behavior. A study by Verhaegen et al. (1985) looked at three groups of workers in wire mills. The first group comprised those who had been directly involved in events which led to the accident (the "active" group). The second group ("passive") were those who had only been involved indirectly ("innocent bystanders") and the third group were a control group who had not been involved in accidents at all.

A series of interviews and questionnaires was given to a sample from each group to address the following issues:

1. Extent of risk-taking behavior
2. Perceived danger of work (risk)
3. Use of personal protective equipment
4. Discomfort of personal protective equipment
5. Positive attitude toward safety department
6. Perception that accidents were random in nature

The results indicated significant differences among the groups for issues 1, 2, and 5. The "active" group had a significantly higher score on risk taking behavior and a lower score for perceived danger of the work (risk) compared with the other two groups. Both active and passive accident groups had a more positive view of the safety department (presumably because of their involvement following accidents). These results suggest a definite relationship among risk perception, risk taking, and an increased likelihood of accidents.

From the perspective of the CPI, this result suggests that it would be valuable to carry out a survey of the perceptions of the workforce with regard to the risks associated with different aspects of plant operations (both field and control room tasks). These perceptions could then be compared with objectively based measures (from risk assessments and accident reports). Where discrepancies exist, appropriate training and information could be provided to ensure that the subjective risk perceptions of personnel were in line with the actual levels of risk associated with the plant operations.

3.6.2.3. *Risk Homeostasis Theory (RHT)*

The somewhat controversial theory of risk homeostasis is relevant to a discussion of risk taking. RHT was developed initially in the area of driving behavior (Wilde, 1984). The theory states that accident rates are not determined by actual levels of intrinsic risk but by the levels of risk acceptable to individuals in the situation. The theory implies that people adjust their risk-taking behavior to maintain a constant level of perceived risk. Thus, if improved safety measures are introduced (e.g., better guarding, improved protection systems), then individuals will behave in a more risky fashion in order to maintain their accustomed levels of risk.

The basis of RHT is set out in Figure 3.4. Individual levels of accepted risk are said to be determined by the costs and benefits of risky and cautious behavior, as set out in box a.

This target level of risk is compared against two sources of information. The first of these is the perceived effect of some risk reducing intervention in the work environment, that is, a change in the system's PIFs such as design changes, as opposed to a change in motivation to behave more safely (see box c). The second source of information against which the individual compares target levels of risk are his or her perceptions of the general levels of risk associated with the job being performed (box d). On the basis of these perceptions of risk, the worker is then said to modify his or her behavior to maintain the level of risk at the same target value as it was prior to the interventions (box f). Taken across a large number of individuals these changes in behavior have an effect on the overall accident rate in the population, for example, within a particular facility (box g). Following a time delay (box h) this in turn will be perceived as a change in the general levels of accident risk, via box d, thus completing the overall control loop.

The implications of RHT, if it proved to be universally true, would be disturbing from the perspective of human factors. The implication is that any interventions to change systems factors, as indicated by the systems induced error view set out in Chapters 1 and 2, would be canceled out by increased risk taking by workers. Needless to say, RHT has provoked considerable controversy among human factors specialists (see, e.g., Wilde, 1984; McKenna, 1985). Most of the debate has centered around differing interpretations of the evidence for reductions in accident levels following the introduction of improved safety systems. Opponents of RHT have pointed to extensive studies showing that people are generally very poor at estimating the magnitude of risk (e.g.,

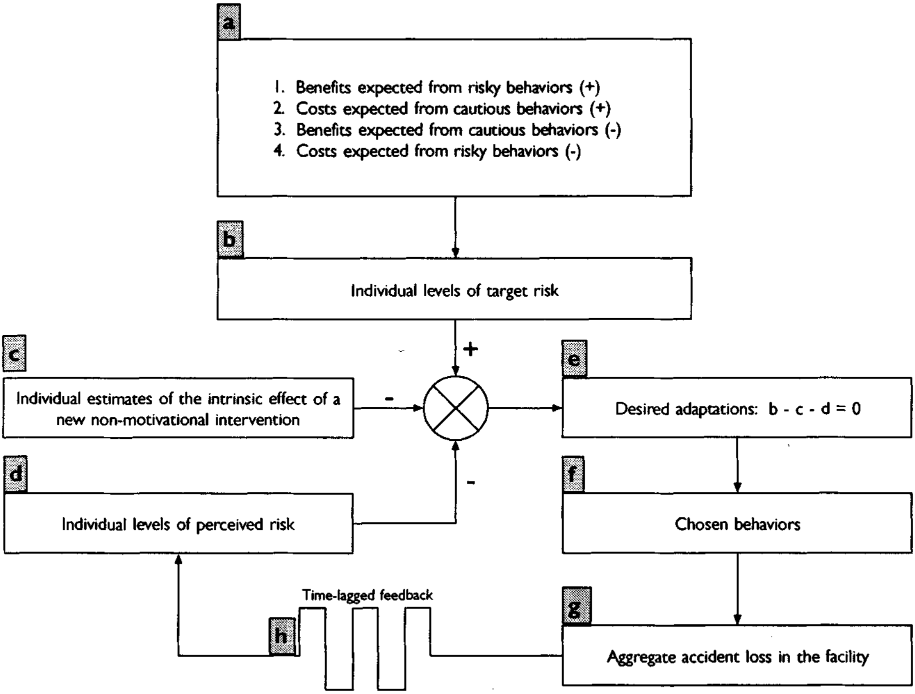

FIGURE 3.4: **Risk Homeostasis Model (Wilde, 1982).**

Slovic et al., 1981), and hence are unlikely to be able to modify their behavior on the basis of objective changes in risk potential. Because of the difficulty of accurately assigning causes to effects, with the sources of data available, it is probable that the theory cannot be proved or disproved on the basis of data alone.

A major difficulty in assessing the applicability of RHT to tasks in the CPI is that most of the technical work which has been carried out on the theory has been in the driving domain. For example, a major focus has been on whether or not the introduction of seatbelts has actually led to a decrease in fatalities or has been compensated for by riskier driving. There are reasons for believing that RHT is unlikely to apply directly to CPI tasks such as control room operations, maintenance or field operations. First, unlike driving, systems interventions that will increase the effectiveness of human performance (e.g., improved training, better display of process information, clearer procedures) will not necessarily encourage the worker to operate the plant "closer to the limits." Even in areas such as maintenance, where the worker is closer to the hardware and has more discretion with regard to how a job is performed, it is difficult to see how improvements in the factors discussed in this book would lead to greater risk taking. In addition, because of the fact that there are considerable differences in the CPI between different processes and the way in which plants are operated, it would be difficult for a worker to arrive at an acceptable level of risky behavior purely on the basis of feedback from the accident rate in the CPI as a whole.

It could be argued that the presence of enhanced protection systems could lead to a plant being operated to its operational limits in order to obtain better yields in the expectation that, if the process entered a dangerous state, it would be tripped automatically. However, the loss of availability that could arise from such a strategy would discourage this type of behavior

In summary, the application of the RHT model to the CPI may by questionable. Certainly, it provides no compelling arguments against the measures for optimizing human reliability which are proposed in this book.

3.6.2.4. *Locus of Control*

The term "locus of control" refers to the tendency of individuals to ascribe the causes of things that happen to them either to external or to internal events. Such individuals are referred to as "externals" or "internals" respectively. Some research results point to the relevance of this dimension to an process worker's response under stress. "Internals" are more likely to seek information about a problem and to attempt to control it themselves. "Externals," on the other hand, are more likely to assume that the problem is out of their immediate control and attempt to get assistance from their colleagues. In an emergency situation, "internals" would be expected to respond better than "externals" because they may have a built-in coping mechanism (i.e., they feel their actions can significantly affect what happens to them). "Externals," on the other hand, may feel their actions can do little to control the situation. A study by Gertman et al. (1985) has provided support for the superior performance of "internals" during nuclear power emergencies. This finding may also apply to CPI operations.

3.6.2.5. *Emotional Control*

This is defined as the tendency to inhibit emotional responses during a crisis (Roger and Nesshoever, 1987). The scale which measures this concept has four factors, namely:

- *Rehearsal*—a preoccupation to ruminate on past events
- *Emotional inhibition*—a tendency to conceal emotions
- *Aggressive control*—a tendency to inhibit aggressive responses
- *Benign control*—a tendency not to say upsetting things

Emotional control is likely to maintain good team communications, particularly at times when the team receives negative feedback about its performance.

3.6.2.6. Type A versus Type B Personality Type

Type B personality is characterized by a relaxed, unhurried, satisfied approach to life and work, in which strivings for achievement tend to flow with the stream of life rather than against it. A type A personality is related to strivings for achievement, and preoccupation with time and success even if against the flow of the environment (Friedman and Rosenman, 1974). A type A personality is considered to be less effective under stress than type B, as the former is characterized by preoccupation with time and success, plus restlessness, and feelings of being pressured (Orpen, 1982)

It is worth pointing out, however, that personality traits which do not provide people with adequate resources to maintain performance under stress, may compensate by supporting other activities during normal operations. For instance, "externals" may be more cautious than "internals" and take no chances to risk plant safety, while type A personalities may have a greater motivation to progress in their jobs and perfect their skills than type B personalities. Depending on the type of task, some personality traits will produce better performance than others. More research would be needed to develop a better understanding of the relationships between types of task and preferable personality styles.

3.6.3. Physical Condition and Age

Conditions of health and age play an important role in human performance. Job demands will determine the general fitness and age of the workers to be employed for a particular job. Recent illness can affect the level of alertness, the required concentration on the job, and the capability to cope with high workload.

A considerable area of research has focused on the way in which age can affect performance. This has been prompted by the increasing age of the general workforce. In general, the effects of age on performance will be determined by two factors, namely, characteristics of the particular task and level of experience with it. Literature reviewed by Murrell (1965) has identified four biological changes which take place with age, namely:

- A decrease in visual acuity and speed of discrimination which may affect the size of detail which can be seen and the ability to read fine scales
- A decrease in the capacity to process information on the control panel
- A loss of working memory which may affect the amount of information that can be retained for long time periods
- A tendency for greater manual variability which affects performance of machine-paced tasks, particularly in the manufacturing industry

Although these impairments in the performance of older personnel can be the result of biological changes due to age, the level of experience with the job may counteract these changes. Continual practice of a particular job role may cause these age differences to disappear. In addition, older personnel may develop more efficient methods of work and thus minimize the demands of the job.

Griew and Tucker (1958) found that in a machine shop, older men appeared to achieve the same results with fewer control movements than younger men working on similar machines. In a study of pillar drilling (Murrell et al., 1962), the performance of older inexperienced workers was substantially worse than young inexperienced workers, but the performance of older professional drillers obtained from industry was slightly better than that of young drillers. This demonstrates the role of experience in compensating for increasing age. However, this compensation only occurs up to a point, and good management should identify those aspects of the task which make the greatest demands upon the older worker and if possible modify the tasks accordingly. An extensive review of the effects of age on performance is available in Small (1987).

3.7. ORGANIZATIONAL AND SOCIAL FACTORS

The various PIFs discussed so far provide a basis for the control of human error at the level of the individual. This section will consider various factors related to the performance of the team and the management practices related to safety.

3.7.1. Teamwork and Communications

Modern process plants grow increasingly complex with highly coupled unit processes. A result of this tendency is that tasks now often require a team rather than individual effort. Team training becomes increasingly important for the safe and efficient operation of plants. The aim of this section is to identify those PIFs which play a critical role in the collective efforts and communications of process workers.

Given the limited resources that a plant can provide for training, a critical question arises concerning emphasis which must be given to individual or team training. Many accident scenarios involve well-trained personnel who failed to work collectively under the particular conditions of the task. We need, therefore, some guidelines to judge the relevant importance of individual versus team performance for different types of tasks.

Blum and Naylor (1968) reviewed the literature on group versus individual training and proposed a useful rule. For tasks which are highly interrelated and which require a great deal of communication and cooperation among members, it is best to employ team training. With tasks which only place low or moderate communication demands on team members, team training is best if the subtasks are fairly simple, but individual training would be best if the subtasks are quite complex. The method of dividing task demands in task organization and task complexity is useful in examining the role of individual versus team training in accident scenarios.

To judge the quality of team performance it is necessary to examine the following PIFs: distribution of workload, clarity of responsibilities, communications, team structure and leadership, and finally, group planning and orientation.

3.7.1.1. Distribution of Workload

The distribution of workload among the members of the team will determine the extent of task overload or task underload for each person. It is widely recognized that reliability decreases when people have too much or too little to do. The incident which is described below occurred because of suboptimal allocation of tasks to team members.

Example 3.10. Effects of Overload Due to Poor Organization of Work (Kletz, 1994b)

Plant foremen sometimes suffer from task overload, in that they are expected to handle more jobs than one person can reasonably cope with. For example, two jobs had to be carried out simultaneously in the same pipe trench, 60 feet apart. At 8:00 A.M., the foreman gave permission to the welders to work on the construction of a new pipeline. At 12:00 noon, he signed a work permit for removing a blind from an oil line, making the assumption that the welders would by this time be more than 50 feet from the site of the slip-plate. As he was already very busy on the operating plant, he did not visit the pipe trench, which was about 1500 feet away. Although the pipeline had been emptied, a few gallons of light oil remained and ran out when the slip-plate was broken. The oil spread over the surface of the water in the pipe trench and was ignited by the welders. The man removing the slip-plate was killed. It was unrealistic to expect a foreman to look after normal operations and simultaneously supervise construction work at a distant site.

On the other hand, when workers are seriously under-loaded, they might not be very alert to changing process conditions. Many of the problems of plant automation are common to other situations of task underload. To increase the level of activity in monitoring tasks, additional tasks can be assigned, such as calculating the consumption of fuels, the life of a catalyst, the efficiency of the furnace and so on. Meister (1979) provides a summary of research on team organization.

3.7.1.2. Clarity of Responsibilities

Specifying the amount of workload appropriate for a worker is not enough. The kind of responsibilities assigned must be clearly specified in both everyday duties and emergency situations. In this context, one can distinguish between two situations, namely, "role ambiguity" and "role conflict." Role ambiguity exists (Kahn, 1974a) when an individual has inadequate information about his role at work. This may reflect a lack of clarity about work objectives, about colleagues" expectations, and about the scope and responsibilities of the job. Kahn et al. (1964) and Kahn and French (1970) have defined role conflict as "the simultaneous occurrence of two or more sets of pressures such that compliance with one would make compliance with another more difficult." For instance, conflict may arise when a manager instructs the worker to carry out a particular action which is at variance with instructions given by the worker's foreman.

Responsibility for each item of equipment should be clearly defined at manager, foreman, and worker level and only the men responsible for each item should operate it. If different workers are allowed to operate the same equipment then sooner or later an accident will occur (see Example 1.27).

3.7.1.3. Communications

Even when responsibilities have been assigned in a clear manner, people may fail to tell their colleagues what they need to know, or may misunderstand a message. The following two incidents were due to failures of communication.

Example 3.11. An Accident Due to Misunderstood Communications (Kletz, 1994b)

In one incident, the laboratory staff were asked to analyze the atmosphere in a tanker to see if any hydrocarbon was present. The staff regularly analyzed the atmosphere inside LPG tank trucks to see if any oxygen was present. Owing to a misunderstanding they assumed that an oxygen analysis was required on this occasion and reported over the phone that "none had been detected." The worker assumed that no hydrocarbon had been detected and sent the tank truck for repair. Fortunately the garage carried out their own check analysis.

Example 3.12. Absence of Communications (Kletz, 1994b)

In another incident, a maintenance foreman was asked to look at a faulty cooling water pump. He decided that, to prevent damage to the machine, it was essential to reduce its speed immediately. He did so, but did not tell any of the operating team immediately. The cooling water rate fell, the process was upset and a leak developed in a cooler.

3.7.1.4. Authority and Leadership

The type of power and social relationships in a group will also affect the overall performance. Although a formal status hierarchy is specified for each team by the plant management, it is well documented that groups have their own informal status structure which may be different from the formal one. In everyday duties it might be difficult to detect any contradictions between formal and informal status hierarchies. In an emergency situation, however, where different interpretations of the situation may be reached, such status problems may create difficulties with regard to whose opinion is followed.

The way that a group handles staff disagreement is also very critical. Performance may be hampered by what has often been called "reactance." The notion is that an individual with a high sense of competence will require freedom to express that ability. If this is denied and the competent person is "relabeled" in a subordinate position, performance will be severely impaired by a tendency to prove "how much better things would have been, if they had been done his or her way."

3.7.1.5. Group Planning and Orientation

In an emergency situation, the team will have to spend some time in planning the right strategy to attack the problem and then allocate responsibilities to team members. The extent of group planing and task orientation in the beginning of a process transient will determine the success of the overall performance. This is not an easy task, since the most common human response to stress is to neglect planning and rush into matters with potentially disastrous results.

3.7.2. Management Policies

Management policies have an all pervasive effect on the activities of individuals at every level in the organization. The safety-related factors at the management level which have been considered in the organizational systems perspective in Chapter 2, will be summarized here to complete the general classification scheme of PIFs.

3.7.2.1. Management Commitment

Not surprisingly, management commitment emerges as the dominant factor influencing safety performance. Commitment needs to be present in a tangible form and not merely espoused as part of a company's mission statement. Real commitment is demonstrated by a number cf indicators. For example, line management in each function, operations, engineering, etc. must be responsible for safety performance of the line function. A safety function in an advisory and audit role should be a distinct organizational function and not put under another grouping where its importance is likely to be diluted. Safety matters should be regularly included in plant operating decisions and top management officials should visit the work areas and keep daily contact with supervisors and line workers. This will ensure that policies that are promulgated by senior management with regard to safety are actually being implemented at the operational level. Another demonstration of management commitment is the resources that they are prepared to expend on the safety function as compared with production

The general safety management policy that exists in an organization needs to be assessed proactively and continuously. Several systems are available—the International Safety Rating System (ISRS)—which attempt to provide a comprehensive audit of safety management activities. Further evidence of a commitment to proactive safety methods is the use of extensive "what-if" and simulation exercises in order to determine the weak points in the defenses of an organization. The existence of such exercises indicates that the organization is actively examining its safety capabilities

3.7.2.2. *Dangers of a "Rule Book" Culture*

Many organizations that have evolved over a long period of time come to believe that the system of safety rules that they have developed is invulnerable to human error. The existence of a "rule book" culture can produce a complacent attitude which assumes that if the rules are followed then accidents are impossible. This is based on the belief that a rigid set of rules will cover every contingency and that interpretation by individuals to cover unanticipated situations will never be required. Of course, all rules will at some time require such interpretation, and the need for this should be accepted and built into the system.

Although rules and procedures are a necessary and indeed essential aspect of safety, they need to be regularly reviewed and updated in the light of feedback from operational experience. Unfortunately, such feedback loops become less and less effective with time, and hence need to be reviewed regularly, preferably by an independent third party

3.7.2.3. *Overreliance on Technical Safety Methods*

In order to achieve the high levels of safety necessary in high risk industries, predictive assessment techniques such as chemical process quantitative risk analysis (CPQRA), hazard and operability studies (HAZOPs), and failure modes effects and criticality analysis (FMECA) are often used. Although these approaches have considerable value, they need to be supplemented with two other perspectives in order to be effective. The first of these is an explicit recognition that human as well as technical failures need to be modeled and assessed, with particular emphasis on "higher level" human functions such as diagnostic and decision making errors. Failures of this type can have substantial effects on the safety of hazardous systems because of their capacity to overcome engineering safeguards. It is also necessary to be aware that any predictive technical analysis of a system makes certain (usually implicit) assumptions about the way the plant will be operated, what sort of quality assurance systems will be in operation and so on. These assumptions relate to human aspects of the system such as the way it is managed, and the operating philosophy with regard to safety versus profitability that is applied. If these assumptions are incorrect (e.g., there may have been a change in management policy) then the technical analysis may no longer be valid. It is therefore necessary to explicitly state the assumptions underlying any technical assessments of risk, and to constantly review these assumptions in the light of possible changes in organizational policies and practices. Effective incident reporting systems are also necessary to reveal sources of risk not considered in the safety analyses.

3.7.2.4. Organizational Learning

It has been stated that "organizations have no memory" (Kletz, 1993) or, to paraphrase George Santayana (in *Life of Reason*, 1905), that "organizations that cannot learn from the past are condemned to repeat their errors in the future." Learning from the past means not only taking specific actions to deal with a problem that has caused a significant injury or loss of property, but also learning to identify the underlying causes of error and the lessons that can be learned from near misses. Near misses are usually far more frequent than actual accidents, and they provide an early warning of underlying problems that sooner or later will lead to an accident.

Nearly all major disasters provide ample evidence of the failures of organizations to learn from their own or other organizations' experience. In the case of Three Mile Island for example, a similar accident had occurred some months before at the similarly designed Davis Besse plant, but correct worker intervention had averted an accident.

In these and many other cases, there are several reasons why organizations did not learn from experience. Incident reporting systems almost always concentrate on the what rather than the why of what happened. Thus, there is little possibility of identifying recurrent root causes so that countermeasures can be developed. Where effective reporting systems do exist, their findings may not be brought to the attention of policy makers, or it may be that the underlying causes are recognized but incorrect trade-offs are made between the cost of fixing the problems and the risks of maintaining profitability by continuing to operate the system. Example 1.28 illustrates the effects of information on incidents not being widely distributed. Another frequent cause of failing to learn lessons is a "blame culture" which discourages individuals from providing information on long standing system problems which cause frequent near misses

Chapter 6 discusses the ways in which feedback for operational experience can be enhanced by improved data collection and root cause analysis techniques. An effective method of learning from operational experience is the analysis of accidents and near misses to identify the root causes of human errors. However, this cannot be achieved unless a comprehensive communication system exists for transmitting the findings of accident analysis and incident reports to higher levels in the organization. For example, the results of causal analyses of accidents should be provided for the developers of procedures and operating instructions, and should provide inputs to both initial and refresher training. It is important that senior management is provided with feedback from operational experience, even if this is in summary form, so that they are aware of the underlying problems that may potentially compromise safety.

3.8. INTERACTION OF PERFORMANCE-INFLUENCING FACTORS

The various PIFs listed so far have been considered individually from the point of view of their potential to affect human reliability. In a real CPI environment, however, the individual is working under a combination of PIFs of different qualities. The overall influences of a combination of PIFs may be different than the sum of the influences. It should be noted that PIFs are not automatically associated with human error. PIFs such as quality of procedures, level of time stress, and effectiveness of training, will vary on a continuum from the best practicable (e.g., an ideally designed training program based on a proper training needs analysis) to worst possible (corresponding to no training program at all). When all the PIFs relevant to a particular situation are optimal then performance will be also optimal and error likelihood will each individual PIF, since these factors may interact with each other in complex ways. The result of this interaction can amplify or attenuate the individual effects of the factors on performance.

We have seen, for instance, how worker experience can compensate for increasing age. Management factors such as commitment to safety can also affect the way that workers will trade-off productivity and safety and thus make use of safety procedures and work permits. Other examples can be drawn from the interaction of control panel design and procedures or training. Grouping of process information, for instance, is related to the type of strategy that is adopted, which in turn is dependent on the type of procedures and training provided. The indicators of the same pressure valve on two different reactors are, in one sense, highly similar. Yet, in another sense, their similarity is low when compared to the similarity between the valve indicator and the pressure indicator on the input side of a reactor. The latter indicators, belonging to a single system, are more likely to be causally related in a failure and thus belong to the same fault cluster. The optimum way of structuring control panel information will depend on the style and type of strategies adopted by the different individuals.

Although the issue of PIF interactions has long been recognized by human factors researchers, little has been done to develop practical recommendations. This is partially a result of the large number of possible PIF combinations and the complexity of their interactions. One of the most effective ways of studying this interaction is through an in-company human factors study which will use operational feedback to evaluate the results of design and human factors innovations.

3.9. VARIABILITY OF HUMAN PERFORMANCE DURING NORMAL AND EMERGENCY SITUATIONS

This section examines the role of PIFs in human reliability during emergency situations as compared to everyday duties. In general, any deficiencies in the quality of PIFs can maximize the adverse effects on performance, because the workers are operating under pressure to acquire information, interpret the implications for the safety of the plant, and reach the right decision as quickly as possible before any serious consequences ensue. A number of phenomena which occur under stress such as rigidity of problem solving, and polarization of thinking, can change the effects of PIFs because they can make the worker more vulnerable to error. It is necessary, therefore, to understand how people behave under conditions of high stress in order to evaluate the role of each PIF.

An emergency situation may display the following general characteristics:

- High-risk environment
- High time pressure
- High task loading, task complexity
- Unfamiliar process conditions
- High noise level due to alarms
- Long working hours to complete the task

The extent to which a particular combination of such "operating environment" factors will be perceived by the workers as being stressful will depend on the available resources such as the quality of the control panel, procedures, training, organizational and social factors, and, finally, the individual characteristics of the workers. The outcome of this transaction between stress factors and coping resources will influence the onset of worker stress. Situations are not stressful merely because of the presence of a number of external stressors, but because they are perceived as such by workers.

The definition of what constitutes a stressor is also an important issue. So far, we have considered only external stressors stemming from the demands of the operating environment. Deficiencies in the design of the control panel, procedures, training, and problems in the area of teamwork and safety management can also cause stress. Such internal stressors can produce conflicting or ambiguous information, worker overload, production-safety conflicts, ambiguity in the role of team members, and poor communication and team coordination. This in turn can have an adverse effect on human reliability. It is the quality of these PIFs which will determine whether they will have a negative or positive effect. Workers will be placed under high stress when they perceive their resources as insufficient to cope with the emergency situation.

Studies of performance under stress have taken three approaches. The first source of data comes from laboratory-based studies which have investigated the effects of only a single external stressor (e.g., noise or heat), upon relatively simple tasks, that is, choice reaction tasks (see Hartley et al., 1989, for a comprehensive review). The second and possibly richest source of data comes from the analysis of real accidents. Studies by Kletz (1994b), Reason and Mycieska (1982), and Dixon (1976, 1987) belong to this approach. Typically, such analyses depend on the level of detail supplied in the reports or the accuracy of the memory of the participants. The retrospective analyses may also be subject to the effects of the rationalizing "hindsight" bias. The final source of data comes from the use of high fidelity plant simulators (Woods, 1982; Norros and Sammatti, 1986; Reinartz, 1989). The difficulties of this approach include the high costs involved in using the simulator and employing experienced teams as subjects, and the degree of stress induced by artificial simulations.

A study by Kontogiannis and Lucas (1990) has reviewed these approaches and developed a classification of cognitive phenomena which occur under high stress. This is presented in Figure 3.5. The classification was developed by examining a number of incidents from various industrial sectors. The cognitive phenomena illustrate in a practical manner the psychological mechanisms which can precipitate errors under stress.

They can also explain why the role of PIFs can vary in normal versus emergency situations depending upon the set of cognitive phenomena that will be brought into play. Because these phenomena can be unique for each individual, greater differences in human performance during an emergency will be found than in a normal situation. Finally, the classification of cognitive phenomena is useful in narrowing down those aspects of PIFs which play a greater role in human performance under stress. For instance, "grouping of information" and "overview of critical parameters" are two aspects of control panel design which can be optimized to reduce the likelihood of the worker developing "cognitive tunnel vision." With respect to procedures design, the quality of checks and the specification of entry and exit conditions can also prompt the worker to consider alternative hypotheses.

PHENOMENA	FEATURES
Defensive avoidance	Can take a number of forms. For instance, a person could become selectively inattentive to threatening cues and avoid thinking about the dangers through distracting activities. Another form of defensive avoidance is "passing the buck" where someone else is relied upon to make the decision.
Reinforced group conformity	The tendency of a group to protect its own consensus by putting pressure on those members who disagree, and by screening out external information which might break the complacency of the group.
Increased risk taking	Individuals tend to take greater risks when they operate within a group rather than alone. Various explanations have been suggested, namely: the illusion that the system they control is invulnerable, the diffusion of responsibility for any potential problems, the presence of persuasive persons who may take risky positions and the increased familiarization of the problem through discussions.
Dwelling in the past	Groups under stress tend to concentrate on explaining facts which have already been superseded by more recent events.
Tendency to overcontrol the situation	People tend to try to overcontrol the situation rather than delegate responsibility.
Adopt a "wait and see" strategy	As consequences of the crisis become more critical, people appear to be more reluctant to make an immediate decision, and wait to obtain redundant information.
Temporary mental paralysis	The short lived incapacitation of the capability of making use of available information. Postulated as being due to the sudden switch from under- to overstimulation at times of crises
Reduced concentration span	Concentration, that is, the ability to deploy attention on demand decreases with stress.
Cognitive "tunnel vision"	This is also known as "hypothesis anchoring" because the worker tends to seek information which confirms the initially formulated hypothesis about the state of the process, and to disregard information which dis-confirms it.
Rigidity of problem-solving	The tendency to use off-the-shelf solutions which are not necessarily the most efficient.
Polarization of thinking	The tendency to explain the problem by a single global cause rather than a combination of causes.
Encystment and thematic vagabonding	Thematic vagabonding refers to a case where a person's thoughts flit among issues, treating each superficially. Encystment occurs when topics are dwelt upon to excess and small details are attended to while other more important issues are disregarded.
Stereotype takeover	Reversion to an habitual or preprogrammed mode of behaviour derived from past experience with a similar, yet in some respects different, situation.
Hypervigilance	Panic occurs leading to disruption of a person's thoughts. A person may fail to recognize all the alternatives open to him and latch onto a hastily contrived approach that appears to offer and immediate solution.

FIGURE 3.5. **Individual and Cognitive Phenomena under Stress (Kontogiannis and**

3.10. SUMMARY

This chapter has reviewed various PIFs which determine the likelihood of human error in the CPI. The list of PIFs in Table 3.1 can be used by engineers and managers to evaluate and audit existing work systems, analyze process incidents and generate error reduction strategies in conjunction with the techniques described in Chapters 4 and 5.

Throughout this chapter it has been argued that the effects of PIFs on human performance will be determined by the characteristics of the task (e.g., process monitoring, procedures-following, diagnosis, planning, manual control). However, many process control tasks involve a combination of such features, and making it difficult to identify their precise effects. To overcome such problems, Chapter 4 presents a number of task analysis methodologies which redescribe complex control tasks into more detailed task elements whose characteristics can be more easily identified and classified in accordance with the previous dimensions. The methodology described in Chapter 4 will assist in applying the knowledge of the effects of PIFs on specific process control tasks. The use of the PIF evaluation approach in the assessment of existing systems can be achieved using the systematic procedures associated with the TRIPOD, HFAM, and HSE approaches described in Chapter 2.