

Understanding Human Behaviour and Error

David Embrey

Human Reliability Associates
1, School House, Higher Lane,
Dalton, Wigan,
Lancashire. WN8 7RP

1. The Skill, Rule and Knowledge Based Classification

An influential classification of the different types of information processing involved in industrial tasks was developed by J. Rasmussen of the Risø Laboratory in Denmark. This scheme provides a useful framework for identifying the types of error likely to occur in different operational situations, or within different aspects of the same task where different types of information processing demands on the individual may occur. The classification system, known as the Skill, Rule, Knowledge based (SRK) approach is described in a number of publications, e.g. Rasmussen (1979, 1982, 1987), Reason (1990). An extensive discussion of Rasmussen's influential work in this area is contained in Goodstein et al (1988) which also contains a comprehensive bibliography.

The terms skill, rule and knowledge based information processing refer to the degree of conscious control exercised by the individual over his or her activities. Figure 1 contrasts two extreme cases. In the knowledge based mode, the human carries out a task in an almost completely conscious manner. This would occur in a situation where a beginner was performing the task (e.g. a trainee process worker) or where an experienced individual was faced with a completely novel situation. In either of these cases, the worker would have to exert considerable mental effort to assess the situation, and his or her responses are likely to be slow. Also, after each control action, the worker would need to review its effect before taking further action, which would probably further slow down the responses to the situation.

The skill based mode refers to the smooth execution of highly practiced, largely physical actions in which there is virtually no conscious monitoring. Skill based responses are generally initiated by some specific event, e.g. the requirement to operate a valve, which may arise from an alarm, a procedure, or another individual. The highly practiced operation of opening the valve will then be executed largely without conscious thought.

In Figure 2, another category of information processing is identified which involves the use of rules. These rules may have been learned as a result of interacting with the plant, through formal training, or by working with experienced process workers. The level of conscious control is intermediate between that of the knowledge and skill based modes.

Knowledge-Based Conscious	Mode	Skill-Based Automatic	Mode
Unskilled or occasional user		Skilled, regular user	
Novel environment		Familiar environment	
Slow		Fast	
Effortful		Effortless	
Requires considerable feedback		Requires little feedback	
Causes of error: <ul style="list-style-type: none"> • Overload • Manual Variability • Lack of knowledge of modes of use • Lack of awareness of consequences 		Causes of error: <ul style="list-style-type: none"> • Strong habit intrusions • Frequently invoked rule used inappropriately • Situational changes that do not trigger the need to change habits 	

Figure 1: Modes of Interacting with the World (based on Reason, 1990)

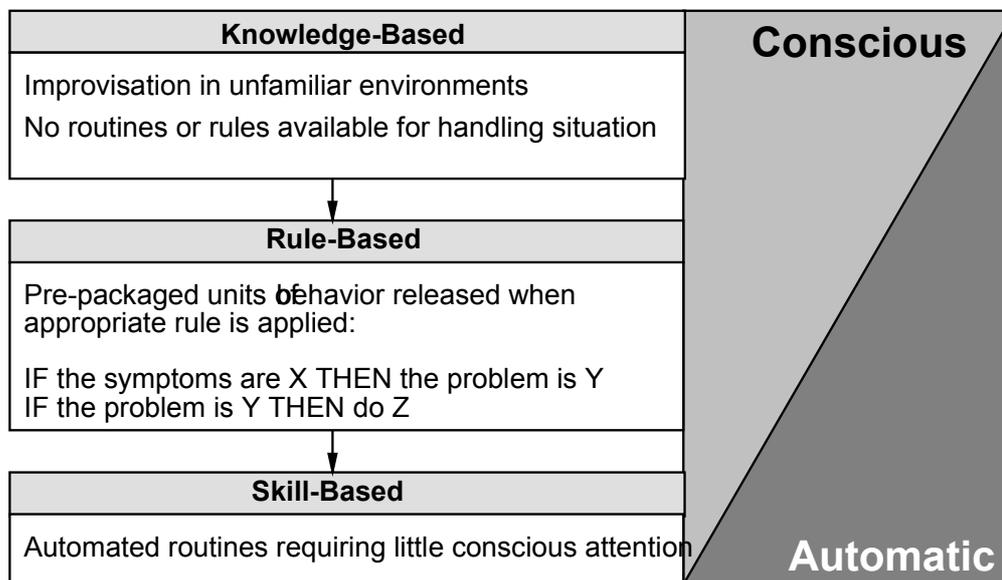


Figure 2: The Continuum Between Conscious and Automatic Behavior (based on Reason, 1990)

2. The Generic Error Modeling System (GEMS)

GEMS is an extension of the SRK Approach and is described in detail in Reason (1990). GEMS is intended to describe how switching occurs between the different types of information processing (skill, rule, knowledge) in tasks. GEMS as shown in Figure 3. The way in which GEMS is applied is illustrated most effectively by means of a specific example.

Consider a process worker monitoring a control panel in a batch processing plant. The worker is executing a series of routine operations such as opening and closing valves and turning on agitators and heaters. Since the worker is highly practiced, he or she will probably be carrying out the valve operations in an automatic skill-based manner only occasionally monitoring the situation at the points indicated by the 'OK?' boxes at the skill based level in Figure 3.

If one of these checks indicates that a problem has occurred, perhaps indicated by an alarm, the worker will then enter the rule based level to determine the nature of the problem. This may involve gathering information from various sources such as dials, chart recorders and VDU screens, which is then used as input to a diagnostic rule of the following form:

<IF> symptoms are X <THEN> cause of the problem is Y

Having established a plausible cause of the problem on the basis of the pattern of indications, an action rule may then be invoked of the following form:

<IF> the cause of the problem is Y <THEN> do Z

If, as a result of applying the action rule, the problem is solved, the worker will then return to the original skill based sequence. If the problem is not resolved, then further information may be gathered, in order to try to identify a pattern of symptoms corresponding to a known cause.

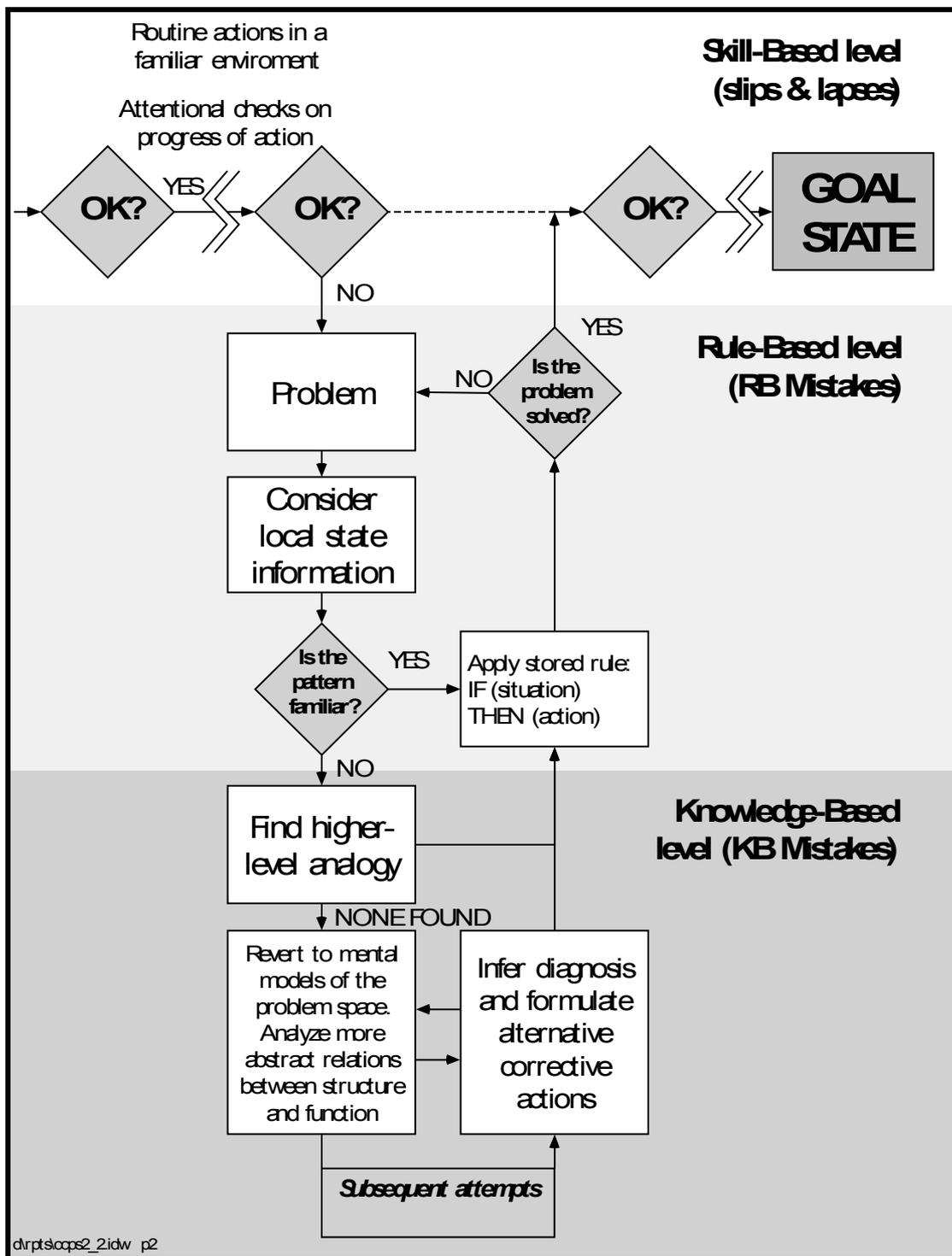


Figure 3: Dynamics of Generic Error Modeling System (GEMS)
(adapted from Reason, 1990)

In the event that the cause of the problem cannot be established by applying any available rule, the worker may then have to revert to the knowledge based level. The first strategy likely to be applied is to attempt to find an analogy between the unfamiliar situation and some of the patterns of events for which rules are available at the rule based level. If such a diagnostic rule can be found which validly applies, the worker will revert back to the rule based level and use the appropriate action rule. However, if a suitable analogy cannot be found, it may be necessary to utilize chemical or engineering knowledge to handle the situation. This process is illustrated in the following example:

Example A: Moving between the Skill, Rule and Knowledge Based Levels in the GEMS Model

While scanning a control panel, a process worker notices that a pressure build-up is occurring during a routine transfer of reactant between the reactors (a skill based check). He first checks if the appropriate valves have been opened (rule based check: if pressure build-up, then transfer line may not have been opened.) Since the valve line-ups appear to be correct, he then moves to the knowledge based level to draw upon other sources of information. The use of a data sheet of the chemical properties of the reactant and a piping diagram at the knowledge based level identify the problem as solidification of the chemical in the line due to low ambient temperature. The formulation of corrective actions involves moving back up to the rule based level to find an appropriate corrective action, for example turning on electric heat tracing at the point in the line where the blockage had occurred. If this action is successful, then the situation reverts to the skill-based level where the problem originally occurred.

This example illustrates the fact that several levels of processing may occur within the same task.

3. Classification of Errors

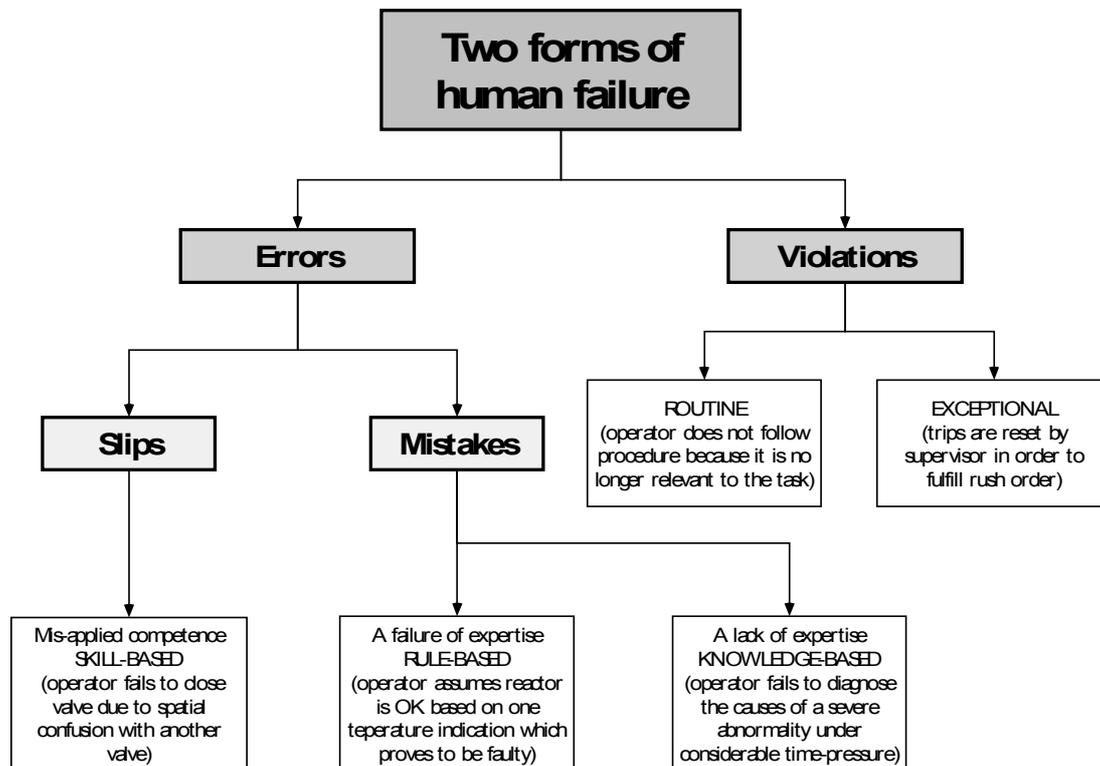
3.1 Slips and mistakes

The categorization set out in Figure 4 is a broad classification of the causes of human failures which can be related to the SRK concepts discussed in the last section. The issue of violations will not be addressed here. The distinction between slips and mistakes was first made by Norman (1981).

Slips are defined as errors in which the intention is correct, but a failure occurring when carrying out the activities required. For

example, a worker may know that a reactor needs to be filled but instead fills a similar reactor nearby. this may occur if the reactors are poorly labeled, or if the worker is confused with regard to the location of the correct reactor. Mistakes, by contrast, arise from an incorrect intention, which leads to an incorrect action sequence, although this may be quite consistent with the wrong intention. An example here would be if a worker wrongly assumed that a reaction was endothermic and applied heat to a reactor, thereby causing overheating. Incorrect intentions may arise from lack of knowledge or inappropriate diagnosis.

In Figure 4, the slips/mistakes distinction is further elaborated by relating it to the Rasmussen SRK classification of performance discussed earlier. Slips can be described as being due to misapplied competence because they are examples of the highly skilled, well practiced activities that are characteristic of the skill-based mode. Mistakes, on the other hand, are largely confined to the rule and knowledge based domains.



**Figure 4: Classification of Human Errors
(adapted from Reason, 1990)**

In the skill-based mode, the individual is able to function very effectively by using 'pre-programmed' sequences of behavior which do not require much conscious control. It is only occasionally necessary to check on progress at particular points when operating in this mode. The price to be paid for this economy of effort is that strong habits can take over when attention to checks is diverted by distractions, and when unfamiliar activities are embedded in a familiar context. This type of slip is called a 'strong but wrong' error.

3.2 Rule based mistakes

With regard to mistakes, two separate mechanisms operate. In the rule-based mode, an error of intention can arise if an incorrect diagnostic rule is used. For example, a worker who has considerable experience in operating a batch reactor may have learned diagnostic rules which are inappropriate for continuous process operations. If he or she attempts to apply these rules to evaluate the cause of a continuous process disturbance, a misdiagnosis could result, which could then lead to an inappropriate action. In other situations, there is a tendency to overuse diagnostic rules that have been successful in the past. Such 'strong' rules are usually applied first, even if they are not necessarily appropriate.

There is a tendency to force the situation into the mold of previous events. Following some modifications to a pump, it was used to transfer liquid. When movement was complete, the worker pressed the stop button on the control panel and saw that the 'pump running' light went out. He also closed a remotely operated valve in the pump delivery line. Several hours later the high-temperature alarm on the pump sounded. Because the worker had stopped the pump and seen the running light go out, he assumed the alarm was faulty and ignored it. Soon afterward there was an explosion in the pump. When the pump was modified, an error was introduced into the circuit. As a result, pressing the stop button did not stop the pump but merely switched off the running light. The pump continued running, overheated, and the material in it decomposed explosively.

In this example, a major contributor to the accident was the worker's assumption that the pump running light being extinguished meant that the pump had stopped even though a high temperature alarm occurred which would usually be associated with an operating pump. The rule 'IF Pump light is extinguished THEN pump is stopped' was so strong that it overcame the evidence from the temperature alarm that the pump was still running. By analogy with the 'strong but wrong' action sequences that can precipitate skill based slips, the inappropriate use of usually successful rules can be described as 'strong but wrong' rule failures. Other types of failure can occur at the rule based level and these are described extensively by Reason (1990).

3.3 Knowledge based mistakes

In the case of knowledge based mistakes, other factors are important. Most of these factors arise from the considerable demands on the information processing capabilities of the individual that are necessary when a situation has to be evaluated from first principles. Given these demands it is not surprising that humans do not perform very well in high stress, unfamiliar situations where they are required to 'think on their feet' in the absence of rules, routines and procedures to handle the situation. Kontogiannis and Embrey (1990) and Reason (1990) describe a wide range of failure modes under these conditions. For example, the 'out of sight, out of mind' syndrome means that only information which is readily available will be used to evaluate the situation. The 'I know I'm right' effect occurs because problem solvers become over-confident in the correctness of their knowledge. A characteristic behavior that occurs during knowledge-based problem solving is 'encystment' where the individual or the operating team become enmeshed in one aspect of the problem to the exclusion of all other considerations (the Three Mile Island accident is a notable example). The opposite form of behavior, 'vagabonding' is also observed, where the overloaded worker gives his attention superficially to one problem after another, without solving any of them. Janis (1972) provide detailed examples of the effects of stress on performance.

3.4 Error recovery

In the skill-based mode, recovery is usually rapid and efficient, because the individual will be aware of the expected outcome of his or her actions and will therefore get early feedback with regard to any slips that have occurred which may have prevented this outcome being achieved. This emphasizes the role of feedback as a critical aspect of error recovery. In the case of mistakes, the mistaken intention tends to be very resistant to disconfirming evidence. People tend to ignore feedback information that does not support their expectations of the situation. This is the basis of the commonly observed 'mindset' syndrome.

4. The Step Ladder Model

The GEMS model is based on a more detailed model of human performance known as the Step Ladder Model developed by Rasmussen, (see Rasmussen 1986) and illustrated in Figure 5. In this model, Rasmussen depicted the various stages that a worker could go through when handling a process disturbance.

Only if the worker has to utilize the knowledge based mode will he or she traverse every information processing stage represented by the boxes connected by the heavy arrows. As in the GEMS model, if the situation is immediately recognized, then a pre-programmed physical response will be executed in the skill based mode (e.g. by moving the process on to the next stage by pressing a button).

If the nature of the problem is not readily apparent, then it might be necessary to go to the rule based level. In this case a diagnostic rule will be applied to identify the state

of the plant and an action rule used to select an appropriate response. Control will revert to the skill based level to actually execute the required actions. More abstract functions such as situation evaluation and planning will only be required at the knowledge based level if the problem cannot not be resolved at the rule based level.

The lighter arrows represent typical short cuts which omit particular stages in the information processing chain. These short cuts may be 'legitimate', and would only lead to errors in certain cases. For example, the worker may erroneously believe that he or she recognizes a pattern of indicators and may immediately execute a skill based response, instead of moving to the rule based level to apply an explicit diagnostic rule. The dotted lines in the diagram indicate the various feedback paths that exist to enable the individual to identify if a particular stage of the processing chain was executed correctly. Thus, if the operating team had planned a strategy to handle a complex plant problem, they would eventually obtain feedback with regard to whether or not the plan was successful. Similar feedback loops exist at the rule and skill based levels, and indicate opportunities for error correction.

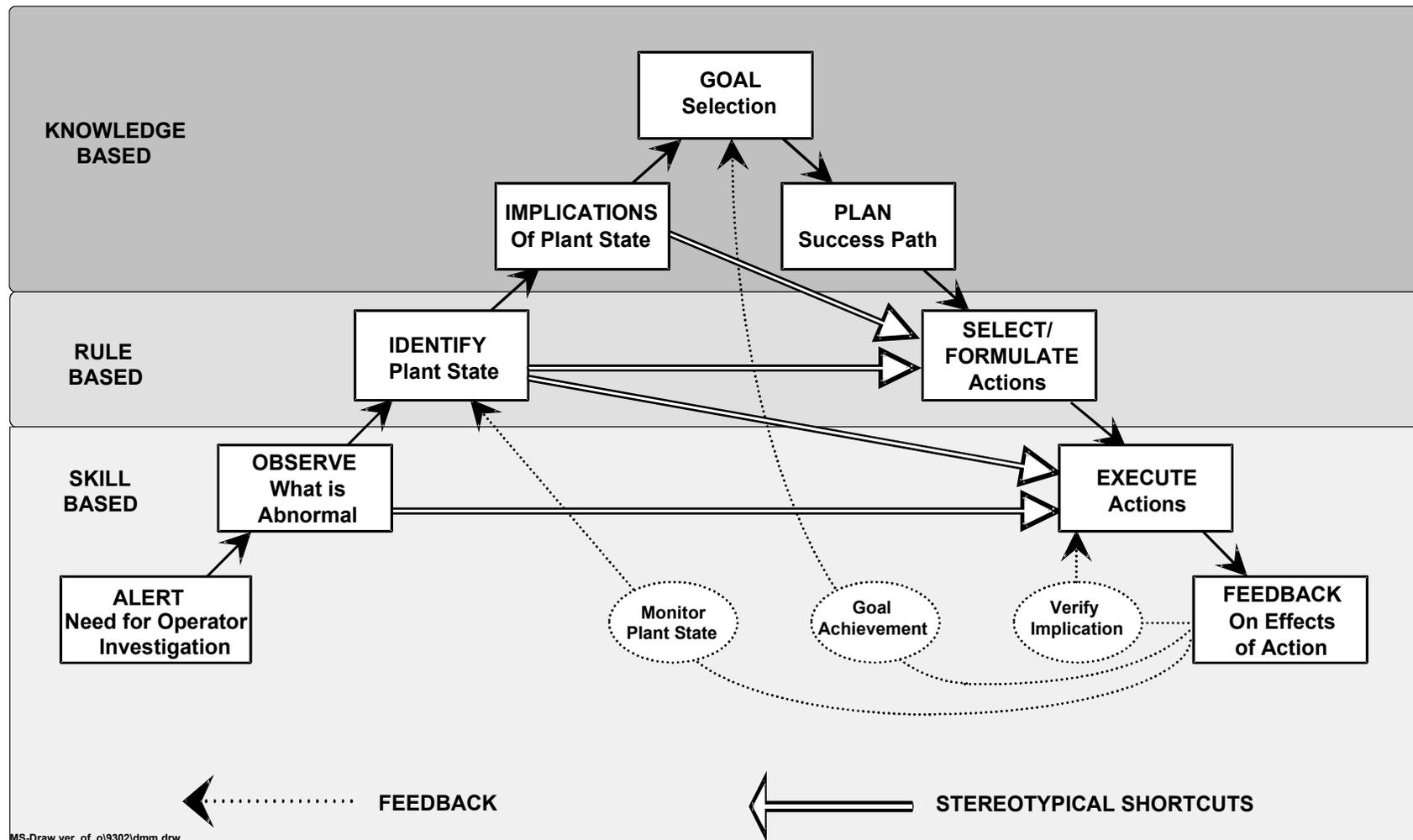


Figure 5: Decision-Making Model (adapted from Rasmussen) including Feedback