A METHOD TO ANALYSE THE SIGNAL PASSED AT DANGER (SPAD)

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ABSTRACT

The principal Agency that manage the railways all around the world have addressed by then the scientific research toward the widening of the human component to understand some incorrect manoeuvres or accidents. The success obtained by these new procedures depends, probably, on the fact that the involved human variables in railway are less large and uncertain respect to road case.

Nevertheless, the simple application of known methodologies, received from other engineering branches, could lead to an extreme simplification.

In order to avoid this problem, the Authors have developed and improved the CREAM method, conceived by Hollnagel, fitting it to SPAD (Signal Passed At Danger) phenomena. This procedure, due to its great flexibility, permits to carry out both retrospective (accident analysis) and anticipatory analyses to estimate risks.

To test the validity of the proposed method, the Authors have performed an example, introducing as analytical instrument to quantify the uncertain variables the Interval Analysis.

The followed results testify a superior evolving state respect to the actual methodologies used by the majority railway agency..

Keywords: SPAD, Human Factors, Interval Analysis, Rail Safety, Railway

1. INTRODUCTION

In any operative context in which the human component is present, there are some variables, differentiated by their own nature but linked each other by more or less evident interactions, that can affect the decisional process result. They can be classified as follows:

- technology;
- normative;
- organization.

In the railway environment, there are anomalous conditions, with a potential danger for the transportation safety, as the one called SPAD (Signal Passed At Danger). The railway signals that can be related to this phenomenon are:

1) low of maneuver;
2) start;
3) protection.

Taking into consideration the essence of these events, it is very easy to be aware of the simplicity of violating the main signal principle according to which “a yellow signal is always followed by a red one” (Cioffi et al., 2001; Migliorini, 2004; SPAD Investigation, 2006). Related to that, the ambush that could occur often is the “erroneous expectation”, i.e. the engine-driver frequently crossing the signal placed on the railway section under evaluation could cross signalling even if it shows an unexpected stop signal.

The possible solution to mitigate these events should be sought not only on technological development of intelligent systems like **SCMT** (**S**ystem **C**ontrol **M**ovement **T**rain) and **RS** (**S**ignalling **R**epeater) (Trenitalia, 2006).

Moreover, two engine-driver on board could assure more safety conditions.

2. DESCRIPTIVE MODEL FOR HUMAN BEHAVIOUR

The cognitive model we intend to apply is a faithful development of the one proposed by Hollnagel (1998) and better known as CREAM (Cognitive Reliability Engineering Analysis Method) and dedicated predominantly to industrial engineering sectors since it is recognised to possess some characteristics which make it suitable for in-depth analyses. This model goes beyond the logic typical of traditional risk analysis to propose a system of classification within which passage between the various groups occurs through antecedent-consequent links. Its main advantage, among many others, is that it has no predefined route patterns as there are, for example, in a Fault Tree, but rather is a scheme capable of adjustment to suit the requirements of specific analyses and of greater analytical depth should there be sufficient interest and available funds.

The initial stage is fundamental as it is at this point that the environment in which the driving manoeuvre takes place is defined by means of nine indicators known as CPC (Common Performance Conditions). The quantification of these coefficients make it possible to depict one or more scenarios, giving the analyst the chance to extend his investigation by suitably adjusting just a few of the peripheral condition parameters.

To avoid the study becoming unmanageable, including financially, a simplified method (Basic Method) can be used on all the hypothesised scenarios and, subsequently, only those considered critical to road safety would be further analysed. The aim of this is to assign to CPCs a value of an analytical nature which, therefore, derives from data base knowledge about either the nature of the driver or the surrounding environment. To do this, the checks included in most regulations and the fieldwork already mentioned can be taken into account.
It is obvious that passage from one classification group to the next and the choice of the component elements in each can only be effected by an analyst possessing considerable competence in the area under examination or, ideally, by means of deterministic or stochastic parameters, that can easily be measured objectively.

2.1 Common Performance Conditions description

There are only three or four classes of scores whose purpose is to temper any imprecision on the part of the analyst. This will be shown in square brackets at the end of the description of each CPC.

- *Planning Quality:* this covers all issues concerning the maintenance policies of the responsible administrative bodies and covers the quality of railway maintenance, operative promptness, etc. It affects almost all the other CPCs such as *Working Conditions*, *Adequacy of Man-Machine Interaction and Operational Support*, *Availability of Procedures*, *Adequacy of Training and Experience*, *Operators Interaction.* [Very Efficient – Efficient – Inefficient – Deficient].
- *Working Conditions:* concerns the nature of physical conditions such as light, windscreen dazzling, noise, activities which distract from driving, etc. Improved driving conditions lead to a decrease in the *Number of Simultaneous Goals* and an increase in the *Available Time.* Scores may be assigned after gathering information about the habits of drivers or if the track creates a situation of stress and forced risk, whether visibility is good at all hours of the day and throughout the seasons. [Advantageous – Compatible – Incompatible].
- *Adequacy of MMI and Operational Support:* checks the validity of information available through instrumentation, computerised procedures, support supplied by internal controls to simplify driving. It affects the *Number of Simultaneous Goals* and the *Available Time* in that if *Adequacy of MMI* increases, these variables reduce and increase respectively. Any positive effects, e.g. from the modernization of trains, could be evaluate. [Supportive – Adequate – Tolerable – Inappropriate]
- *Availability of Procedures and Planning:* includes operational, emergency and routine procedures. If this indicator assumes a high value, the *Number of Simultaneous Goals* will be smaller and the *Available Time* will increase. Does the nature of the task permit emergency manoeuvres or driving procedures that are not too distant from habitual manoeuvres? [Appropriate – Acceptable – Inappropriate]
- *Number of Simultaneous Actions:* concerns the number of the actions the driver has to do simultaneously such as assessing the effects of his actions, sampling new information, etc. This has a direct impact on *Available Time* in that the two CPCs are

related in inverse proportion. There is a strong dependence on environmental complexity which causes an increase in the number of tasks the driver is required to perform. [Fewer than driver's capacity – Matching current capacity – More than capacity].

- *Available Time:* this means the time the driver has at his disposal to carry out the task in progress within the limits of the dynamics of the process. It is linked to *Working Conditions* in that these deteriorate if the Available Time decreases and for this reason the combination of these two indicators and the *Number of Simultaneous Goals* leads to the well known concept of workload. It is a function of the visibility distance that is available for stopping and, consequently, of travelling speed. [Adequate – Temporarily inadequate – Continuously inadequate]
- *Time of Day - Circadian Rhythm:* this checks the time at which the action take place and, in particular, whether this is out of sync with the driver's circadian rhythm. It's linked to *Working Conditions* and *Available Time,* in that poorer performance means that Available time is reduced. Is the "average" driver being analysed travelling at a time of day in which he would normally be resting? This is difficult to establish. [Day time (adjusted) – Night Time (unadjusted)]
- *Level of Experience:* this involves assessment of the level and quality of the driver's training, meaning his familiarity with new technology, revising old skills, practical experience, driving habit, etc. There will be a direct relationship with *Working Conditions*, *Available Time* and *Crew Collaboration Quality* in that with an increase in experience and training the aforementioned indicators improve. Clearly this CPC regards young or elderly drivers' capacities and has repercussions on visual apparatus especially as regards accommodation length, foveal and peripheral vision. [Adequate, high experience – Adequate, limited experience – Inadequate]
- *Crew Collaboration Quality:* this means the level of interaction between users, i.e. the influence other trains have on individual drivers. This variable directly influences *Working Conditions* since efficient use of resources avoids misunderstandings and reduces delays. Inappropriate behaviour on the part of other drivers could also be included or, on the other hand, scenarios could be imagined in which vehicular traffic is regular. It is certainly difficult to measure but needs to be contemplated in the scenario. [Very Efficient – Efficient – Inefficient - Deficient]

Each of the three or four classes of criterion gives individual CPCs an improved, reduced or insignificant effect on the driver's overall control. Of course the central classes are those considered insignificant in that they don't alter total score even if for these CPCs it is necessary to assess any secondary effects generated by other CPCs.

2.2 Cognitive Failure Probability definition

In short, two distinct categories will group together CPCs thought to have reducing and improving effects on control, those which prove to be insignificant must be further examined in order to identify any correlation with other CPCs. The consequences of this further examination might lead to improved or impaired driver control. Once the scenarios thought to be most critical have been identified, a more detailed research phase can be embarked upon. This involves three stages:

1. Formulation of a profile of the cognitive demands of the activity, i.e. the cognitive activities which characterise each individual action are identified and used to build a profile based on cognitive functions.
2. Identification of the probable errors in cognitive function. The CREAM classification scheme is used to examine the mistakes that might be made.
3. Establishing the probability of specific errors of action. This is achieved by calibrating a set of probabilities of mistakes occurring for simple actions against the impact of performance conditions.

The first phase serves to establish whether the activities involved in the execution of the action depend on specific cognitive functions. The list of cognitive activities prepared by experts over the years can be summarised as follows: *Coordinate, Communicate, Compare, Diagnose, Evaluate, Execute, Identify, Maintain, Monitor, Observe, Plan, Record, Regulate, Scan, Verify.*

It might be useful here to use an instrument which makes it possible to relate the above activities to driving manoeuvres. One of the many methods used in risk analyses could be used for this such as HTA Hierarchical Task Analysis) or, more simply, a Fault Tree. Thus a profile of cognitive demands could be formulated, illustrating cognitive demand percentages on the ordinate and the *Observation*, *Interpretation*, *Planning* and *Execution* function on the abscissa. Defining a cognitive demand profile makes it necessary to underline the demands of each cognitive function in the various phases of the task within the specified activities. In the Application some tables will show the relationships between the four principal cognitive functions and the activities previously listed.

The second step concerns the identification of mistakes within the cognitive functions, which can be done using the cause-effect classification already mentioned. Of course the aim in finding out probable failures is not to establish all possible error modes, but to identify which type is likely to predominate throughout the action. This is where the work carried out in the simplified method of quantification already mentioned becomes very important since it helps the analyst, who in any case must have full knowledge of the nature of the task under examination, to point his enquiry in the right direction.

For the sake of brevity, we will omit details of the classification groups (Pellegrino, 1999; Bosurgi et al., 1999), and will later include error modes, selecting them on the basis of HTA and CPC findings.

Analogously to the profile of cognitive demands it is possible to build a distribution of failures in functions in order to evaluate which of these can compromise performance of the action. A table can be drawn up to correlate cognitive activities to error modes so as to identify the phase of the action with which to associate possible failures.

The third and final step concerns determination of the probability of cognitive failure, known as CFP (Cognitive Failure Probability), quantified after assigning to possible errors a nominal probability using experimental tests. Unfortunately at the moment available data for railways are not associated with the means necessary for the

application of the model. Considering this deficiency and with the aim of applying the procedure, it is possible make up the deficiency with related data.
When available, data from other disciplines can be found in literature and analyzed with the usual methods designed to deal with uncertainties such as stochastic methods; otherwise, when information is more scarce, interval or similar analyses can be employed.

The nominal values must subsequently be corrected as a function of previous phases, in particular the CPC defining phase so as to arrive at measurements for the specific context under study. It must be underlined that these quantifications can easily be included in a Fault Tree or similar in which human behaviour is only one component of the system.

3. MODELS OF UNCERTAINTY

The previous application needs, however, to be enhanced by more efficient analytical support in order to endow this type of procedure with a marked propensity for the resolution of road problems. The grey areas are located principally in the passages through the various HTA steps or between the various classification groups, so the final result is highly dependent on the capacities of the analyst. The difficulties of trying to apply mathematical models to the magnitudes involved lie in the fact that these are blatantly random and, furthermore, being intimately connected with human behaviour, we have no knowledge of the mechanisms that make these interdependent.

Having established the chance nature of these magnitudes, we need to propose back-up analysis procedures that make it possible to overcome the blatant approximations of deterministic mathematics.

Stochastic modelling is certainly the most widely used instrument and involves defining random variables and probability density functions. Within the stochastic context the main aim is to pinpoint the reliability of the system under examination, where by "system" we mean not only the mechanical components as a whole but also, when appropriate, the aspects relating to driver behaviour. Reliability is, therefore, the probability that the system will function adequately over a specific time range and under pre-established environmental conditions.

This definition contains four extremely important concepts which can be summarised as follows:

- reliability is expressed using a real number between 0 and 1;
- it must be established when a component should be considered a failure;
- operative conditions need to be established in that reliability can be greater or lesser according the way the element under consideration is used;
- time of use needs to be specified.

Very often, however, experimental information is lacking and this means that the researcher relies rather heavily on the hypotheses formulated initially and , consequently, arrives at non-verified conclusions.

Thus, when information on these variables is fragmentary, it is necessary to use another approach in evaluating random factors. Elishakoff & Ben Haim (1990) proposed the convex modelling, which is simply a generalization of interval analysis. This theory does not define any measure of probability, but rather specifies sequences of events permitted as a function of the limited information available. It is thought, however, that these objectives can be achieved using instruments such as convex analysis rather than by means of stochastic mathematics in that the information will, in any case, be unhomogeneous and, therefore, insufficient to describe the moments characterising the statistics.

From the above it can be inferred that there is every need to prefer calculation models that are not over-complex so as to limit analytical efforts; nevertheless, if the modelling of some random parameters represents the natural evolution of these procedures, one should tend towards representing functions which summarize most of the parameters involved and this can be refined and validated only by field work.

4. APPLICATION

The objective of the present work is to evaluate the current safety level related to a railway section or even to a whole railway trunk, which could be very important when the railway manager wants to plan the maintenance activities in specific critical points, so optimizing the resources management, especially the financial ones. The following application aims to clarify the introduced criterion (Fisichella, 2006).

Using the prediction procedure method, it is possible to manage different variables than the ones classically considered by railway-engineers. These variables have the peculiarity of considering the drive behaviour in a particular context.

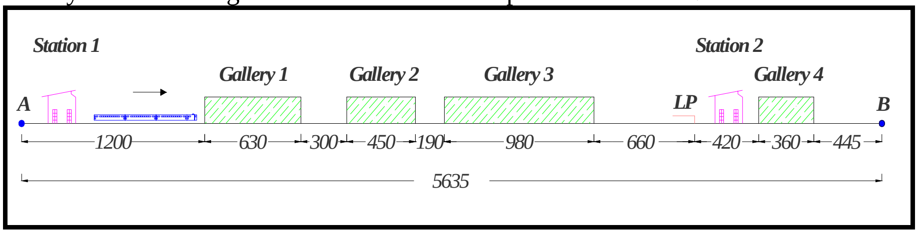

Fig. 1 Analyzed context

To better clarify the introduced criterion, a numerical application is proposed, based on the railway section shown in Fig. 1, with the following main characteristics:

- Trunk's length: about 5.635 m (from A to B)
- Only one binary for both directions with automatic electrical block with encoded currents for the signal repetition on board
- Presence of four tunnels disposed as shown in Fig. 1 and with a length of 630/450/980/360 m respectively
- Presence of two stations of which the first one disabled and the other one functioning with the presence of a motion manager
- Presence of a level crossing
- Longitudinal inclination equal to 4‰ (assumed regular for the whole trunk)
- Various signal system's characteristics, e.g inside and outside tunnels, light signals, etc.

- Locomotive type E 646 equipped with a signalling repeater, air-conditioning and business mobile phone communication
- Corrected Composition train
- Double agents as crew
- Train runs from A to B in night time;
- Expert and rested engine-drivers (with a previous 35 hours at rest and without any visual pathology);
- Infrastructure with lack of maintenance and worsen by low visibility (fog presence) and signals partially hidden among vegetation.

4.1 Evaluation of each CPC level and related effects

Having before described the meaning of the nine CPCs characterizing the context and the related calibration rules, it can be deduced as follows:

Tab 1 - Expected levels for CPCs

CPCs List			
CPC DESCRIPTION	**LEVEL**	**VOTE**	**EXPECTED EFFECT**
Planning quality	Inefficient	2/4	Reduced
Working conditions	Incompatible	1/3	Reduced
Man-machine interface	Supporting	4/4	Improved
Procedures availability and planning	Acceptable	2/3	Not significant
Number of simultaneous actions	According to actual capacity	2/3	Not significant
Available time	Temporarily unsuitable	2/3	Not significant
Day time (circadian rhythm)	Incorrect	1/2	Reduced
Experience Level	Suitable, high experience	3/3	Improved
Crew collaboration quality	Efficient	3/4	Not significant (indirectly improved)

4.1.1 Triple summation calculation and "Control Mode" individualization

Observing the Table 1 is possible to deduce:

$[\Sigma_{reduced}, \Sigma_{not\ significant}, \Sigma_{improved\ +\ not\ significant/indirectly\ improved}] = [3,3,3]$, equivalent to a "scheduled type Control Mode". The explanatory procedure is concluded by the treatment of the three points considered for "Basic Method" and analyzed above. Therefore, the next considerations have to be referred to the "Wide Method".

4.1.2 Constructing the cognitive questions profile

The cognitive questions profile allows to establish if the whole task rises from specific set of cognitive functions. In the predictive model presentation phase it has been introduced a cognitive activities list that could foresee a critical state. Practically, the cognitive activities involved in the running of the examined railway section have to be selected.

- Drive activity can be contained in the following tasks:
- Information Request (SUB TASK 1);
- Realization of relative countermeasure (SUB TASK 2).

- Independently from the execution sequence, the activities related to the examined case are reported in Tab. 2-3 and marked with A and B respectively:

Tab. 2 - Cognitive activity list involved in Information Request

Information Request (Sub Task 1)		
ACTIVITY		(CORRELATED ACTIONS)
A1-Coordinate	•	Setting of instrumentation on board
A2-Communicate	•	Possible phone call with technical support staff present in a witnessed station
A3-Compare	•	Look of external luminous signal with those received into cockpit
A4-Diagnose	•	According to signal information, recognized the attendance by other railway convoy
A5-Evaluate	•	The route's speed, according to signal information and environmental condition
A6-Identify	•	Recognize the information, according to received code
A7-Observe	•	The signal look and the relative prescriptions
A8-Scan	•	Control system's state.

Tab. 3 - Cognitive activity list involved in "Accomplishment" action

Realization of Relative Manoeuvre (Sub Task 2)		
COGNITIVE ACTIVITY		(CORRELATED ACTIONS)
B1- Coordinate	•	Observe the operation command's sequence
B2- Communicate	•	Acknowledge the system with the received code
B3-Execute	•	Reduce the speed based on the received information
B4-Monitor	•	Observe the foreseen timetables
B5-Observe	•	Comply with the possible prescriptions
B6-Record	•	Store the received information, especially the one obtained by observation
B7-Rregulate	•	Regulate the train speed, depending on the environmental conditions
B8-Verify	•	Compatibility between the actual speed and the scheduled one

The HTA (Hierarchical Task Analysis) allows distributing the involved activities inside each route phase. In some tables, reported only in the publications quoted into the Reference, the cognitive actions related to sub tasks, divided into the following categories: Observation, Interpretation, Planning and Execution.

Afterwards, an activity summary must be compiled, by counting the recurrence of each cognitive function for the whole task or for sub tasks (Tab. 4).

Tab. 4 - Cognitive function number global count

Cognitive Function Number Global Count		
FUNCTION TYPE	for SUB TASK 1 + SUB TASK 2	%
OBSERVATION	7	38.9
INTERPRETATION	2	11.1
PLANNING	5	27.8
EXECUTION	4	22.2
TOTAL	18	100.0

4.2 COGNITIVE FUNCTIONS ERRORS IDENTIFICATION

In the last representative phase, a high importance is given to Observation function and then to Planning, Execution and Interpretation.

Combining the cognitive questions profile and the CPCs' results, it is possible to obtain the dominant error type. Based on that it was observed that the control mode suffered a worsening caused by:

- fog;
- night drive condition;
- infrastructural maintenance shortage;
- signals partially covered by vegetation.

Combining these indicators with the cognitive questions profile, it can be seen that the most important antecedent is to be searched inside the Observation category, even if the other groups include potential error modes.

Tab. 5 shows the classification groups containing generals and specifics antecedents creating the starting point for antecedences/consequences links.

In the last column the potential errors representing the analysis starting point have been identified.

Tab 5 - List of possible failure

GROUP	GENERAL ANTECEDENT	SPECIFIC ANTECEDENT	POTENTIAL FAILURE
OBSERVATION	wrong diagnosis	Ambiguous signal	Distort observation
PLANNING	excessive demand	Objective's Wrong Individualization	inadequate planning
EXECUTION	wrong diagnosis	Overload of information	Temporal error
INTERPRETATION	wrong identification	Learning false	Delayed interpretation

Further step is to combine the cognitive activities and the related functions with the corresponding failure mode.

Now, for the sake of brevity, it is not advisable to report the table with all the probable error modes. From the literature quoted in Reference it is possible to draw the failure cognitive function profile, corresponding in this case to the cognitive questions profile, having considered all the cognitive functions.

4.2.1 Specific erroneous actions' probability evaluation

In the next phase, the nominal error type values to be used in the following must be reported. Now, knowing the nominal error type values from literature, it is possible to evaluate the effects due to the CPCs, given the CFPs' nominal values related to the simulated context. Multiplying these values it is possible obtain the weights that represent the worsening or the improvement of final result, related to the considered scenario (Tab. 6).

Tab. 6 - Linking of CPC's effects to relative weights

CPC	LEVEL	OBS.	INT.	PLA.	EXE.
Planning's quality	Inefficient	1,0	1,0	1,0	1,2
Driver's condition	Incompatible	2,0	2,0	1,0	2,0
Man-machine interface	Supporting	0,5	1,0	1,0	1,0
Availability of procedure and planning	Acceptable	1,0	1,0	1,0	1,0
Number of simultaneous actions	As capacity	1,0	1,0	1,0	1,0
Available time	Temporarily inadequate	1,0	1,0	1,0	1,0
Daytime (circadian rhythm)	Unsuitable	1,2	1,2	1,2	1,2
Level of experience	Training-high experience	0,5	0,5	0,5	0,5
Crew collaboration quality	Efficient	1,0	1,0	1,0	1,0
TOTAL WEIGHT of CPCs		**0,6**	**1,2**	**0,6**	**1,4**

The influence of CPCs will be used to adapt the nominal error value (received by literature) on the cognitive functions, as shown in the following table 7.

4.3 Considerations on results

The final CPCs represent the probability that the operator doesn't execute the specific functions in an effective manner.

From the failure probability graphic distribution analysis it can be seen that the delayed interpretation is more dominant than the others.

This means that the errors identified in the sub tasks A4 and B8 are related to Diagnosis and Verification.

Because of the considered particular environment context (fog and vegetation), it can be difficult to locate the presence of possible obstacles (e.g. cars on open level crossing, etc.) in the line trunks following the one used by train, but also to adjust the speed as foreseen in the running table.

Installing safety equipment, as the RS (on board Signal Repeater), can luckily increase the qualitative standard of the railway section, especially when visibility is poor. Notwithstanding, to assure a regular and safe traffic, maintenance has to be considered as priority objective.

So, the result of predictive analysis is very important because allows designers and maintenance people to understand the reasons for human reliability reduction during the established route. The shown method allows canalizing the economic resource according to priorities.

Tab. 7 - Correct CFPs' values

STEP	ACTIVITY	Error Mode	Nominal CFP	Weight	CFP
A1	Coordinate	Inadequate planning	0,01	0,6	0,006
A2	Communicate	Inadequate planning	0,01	0,6	0,006
A3	Compare	Wrong observation	0,001	0,6	0,0006
A4	Diagnose	Delayed interpretation	0,01	1,2	0,012
A5	Evaluation	Inadequate planning	0,01	0,6	0,006
A6	Identify	Wrong observation	0,001	0,6	0,0006
A7	Observe	Wrong observation	0,001	0,6	0,0006
A8	Scan	Wrong observation	0,001	0,6	0,0006
B1	Coordinate	Temporary error	0,003	1,4	0,0042
B2	Communicate	Temporary error	0,003	1,4	0,0042
B3	Execute	Temporary error	0,003	1,4	0,0042
B4	Monitor	Wrong observation	0,001	0,6	0,0006
B5	Observe	Wrong observation	0,001	0,6	0,0006
B6	Record	Wrong observation	0,001	0,6	0,0006
B7	Regulate	Temporary error	0,003	1,4	0,0042
B8	Verify	Delayed interpretation	0,01	1,2	0,012

5. CONCLUSIONS

About the CREAM method's future development, it would be desirable to realize a detailed database containing data and information related to any recorded anomalous events. This can help to investigate all the characteristic aspects of accidental phenomena.

Compared to the other diagnostic instruments, the CREAM method:

- allows analyzing anomalous specific events with dynamism, intuition and rapidity;
- doesn't need staff involvement and/or other people outside the company;
- allows to arrange different study levels connected to economical and temporal resources, number of technical analysis to do, quantity and quality of the acquired data;
- doesn't need to separate the whole process in different phases;
- helps analyst to obtain a quick diagnosis by using simple tables and rules;

- it is an useful instrument to resolve both retrospective and prediction events (basic and extended procedures);
- and still more.

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