

TO DO NO HARM-MEASURING SAFETY PERFORMANCE IN A TRANSITION ECONOMY

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The paper presents some results of an original research regarding the design and development of a set of safety performance benchmarks. This benchmark package was built to take into account the specific characteristics of Romanian economy.

A critical analysis of the past centralised Romanian safety national benchmarking system-based on accidents and occupational diseases statistics – is also performed in the paper. This system was taken as a reference in the building of the new system.

An essential element of the new system is the safety trophic chain (STC). This safety trophic chain could be taken as the main link between old and new. Another central idea of the benchmark system is represented by the safety earned value (SEV). Every action performed regarding safety and health is considered as adding SEV to the system. The cross-checking between SEV and actual costs could be an efficient benchmarking indicator.

GENERAL ASPECTS

Safety must start with one of the first medical principles "to do no harm to your patient". Besides this principle safety must contribute actively to the improvement of health and life conditions at workplace. Safety activities are involving a significant use of resources in order to be performed rightly. The allocation of resources must be justified by results. So, the measurement of safety performance, done through safety benchmarks, plays a central role in every safety management system.

Benchmarks must be connected with action plans, as shown in Figure 1.

SAFETY BENCHMARKING IN A CENTRALISED ECONOMY

Romania had till 1990 a strongly centralised economy. Safety benchmarking was performed by the Labour Department, at the global economy level using essentially two indices:

- Total Accident Rate (TAR);
- Lost Workdays Accident Rate (LWAR);

There were analysed the trends over time for TAR and LWAR benchmarking on:

- economic activities;
- industries;
- enterprises;

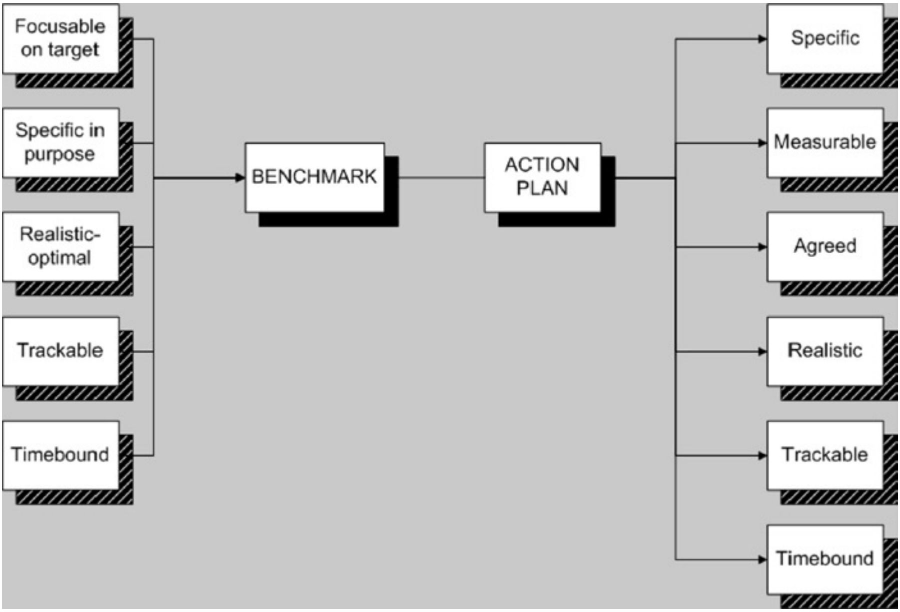

Figure 1. Safety benchmarks and action plans

This benchmarking was leading towards national safety strategies on economic activities and industries levels[1].

The main disadvantage was the centralised approach. The most safety performing enterprises were not rewarded. The less safety performing enterprises were supported in order to improve their safety.

OLD/NEW MODEL — THE SAFETY TROPHIC CHAIN (STC)

Our old-new model is a qualitative one; it follows the transition from the heavily centralised economy towards a market economy where the enterprise is the central factor. This transition must be also visible in the benchmarking process. From a pure statistical benchmark there will be a progress to a multi-criteria, multi-performance benchmark[2], taking into account various workplace aspects.

The safety trophic chain is connecting (chaining) safety at the individual level with safety at the workplace/workteam level and with the general enterprise safety state.

The STC resides at the foundation of the OLD/NEW model.

The central idea in the STC is that, starting with the individual worker's safety — as the STC base and ending at the enterprise level safety, the safety is gained or lost through actions inside the chain[3]. Every safety component of the chain could promote or regress.

Figure 2 presents the STC idea.

Like in the natural trophic chain, the more safety prone structures are surviving, the others are decaying.

Every chain link could be described by two distinct safety values:

- a minimal safety value, sufficient to survive but not to progress;
- an optimal value that allows the progress in the STC;

For example, considering the first chain link, the Individual Worker Safety — the minimal safety is needed by the worker in order not to be injured by incidents. However, the minimal safety is not sufficient to be able to function inside a more evolved structure — the work team. If the safety level is optimal then is possible the progress towards the work team safety concept.

Considering the work team safety, if there could not be realised an optimal safety level, the team would regress towards the individual worker level safety, each worker being focused on his/hers own safety. If the optimal safety level is attained then the STC could progress towards the next level.

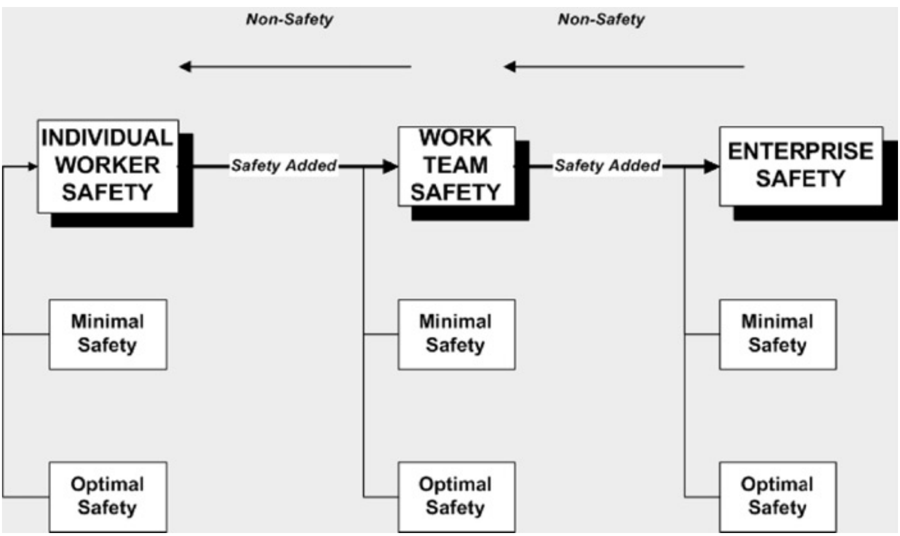

Figure 2. Safety trophic chain

ESSENTIAL ASPECTS OF THE BENCHMARKING METHOD USED INSIDE THE PACKAGE

This method considers that during the work process every activity earns a safety value through the process development.

This value depends essentially on:

- global and local management safety commitment;
- general safety state at the workplace;
- safety training;

The method uses a two-fold structure.

This structure takes into consideration:

- Benchmarking the safety plans at the enterprise and workplace levels – as an essential indicator of the managerial approach (emergency management, management of change and other management aspects correlated with safety are included here);
- Benchmarking specific safety aspects inside the workplace using the milestones method through specific activities — as essential safety indicators at workplace;

Two basic hypotheses were considered:

- Standards of performance are set by industry safety experts against score ranges;
- Judgement on adequacy is based on:
  - risk/safety assessment on site;
  - good practice;

Also, it must be emphasised that the application of the method is based heavily on statistical data collected into specific databases. This data could be used as a pattern for new benchmarking processes.

As shown before there are two stages of application:

- safety plans benchmarking — using Safety Apportioned Efforts (SAE) — safety plans at the workplace level and at the enterprise level are evaluated in order to benchmark the:
  - general operational management;
  - safety management/management of emergencies;
  - management of change[4];
- workplace safety benchmarking — using Safety Earned Value (SEV) — through the benchmarking of specific activities developed there; different parameters like Safety Schedule Variance (SSV), Safety Schedule Performance Index (SSPI), Safety Cost Variance (SCV) and Safety Cost Performance Index (SCPI) are computed and used for benchmarking between units of the same type or between units of different types.

SAFETY PLANS BENCHMARKING

Safety plans benchmarking uses Safety Apportioned Efforts (SAE) as a symbolic relationship between two closely related organizational elements — safety planning at the

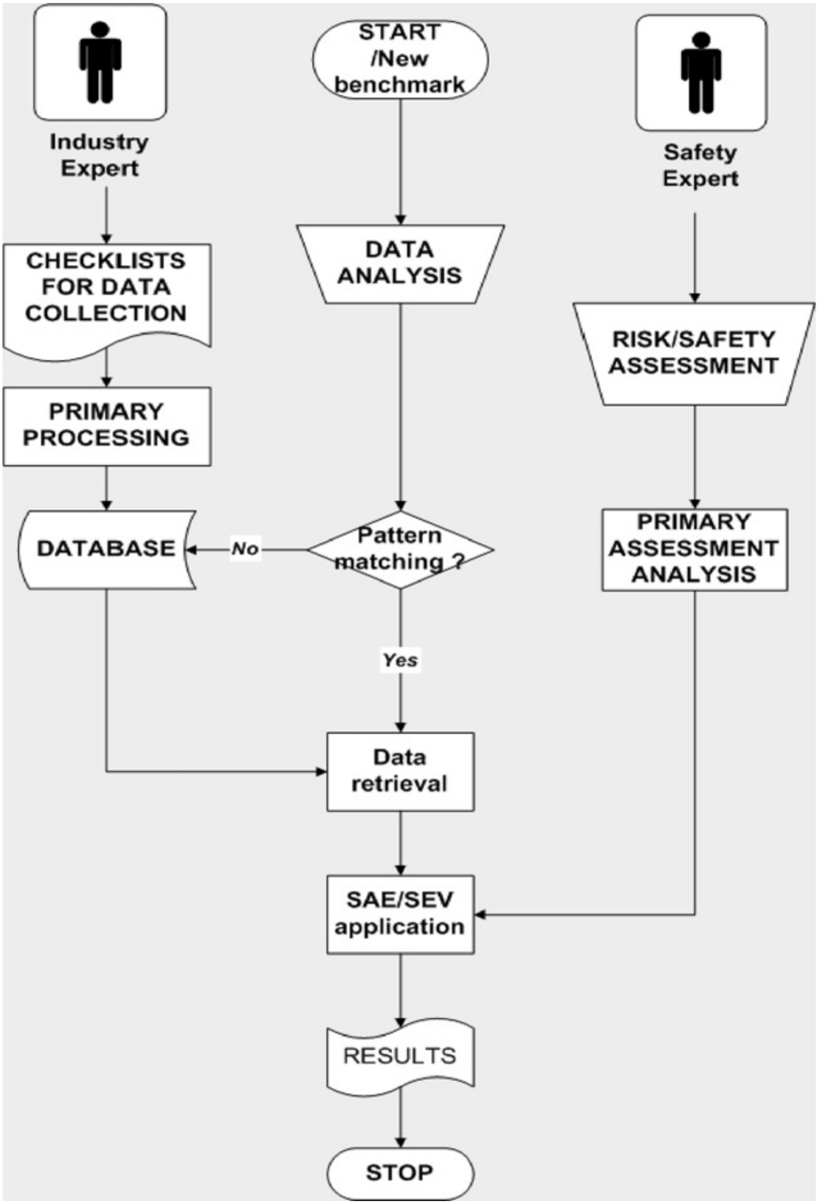

Figure 3. Benchmark phases

workplace level and safety planning at the enterprise level. These two planning and work packages have a cause — effect type of relationship. The related packages have work scope dependency – this dependency is given by the safety level.

The task plans could be:

- sequential — the default case;
- supportive — the optimal case; they also have implied schedule interdependencies, normally stated in a set package.

The Safety Task Plans (STP) which is linked using SAE is essentially a Master Safety Task Plan (MSTP) — at the enterprise level, and a Slave Safety Task Plan (SSTP) at the workplace level. Generally there is a delay between the work scheduled for MSTP and SSTP — this delay factor must be built into the plan[5].

Figure 4 shows an example of these connexions considering the situation of a chemical facility (MSTP) with a welding workplace as SSTP.

The established relationship between MSTP and SSTP during the baseline period could produce a variance (Apportioned Effort) during the actual performance for which the Task Manager has no control. The SSTP variance will be a direct result of the failure to perform as set forth within MSTP[6].

Benchmarking is performed here considering the difference between planned and performed in the following situations:

- variance has no effect on safety and on general performance — score 4 ... 5;
- variance has effect on general performance (delay in resource allocations, etc.) but not in safety — score 2 ... 3;
- variance has effect on general performance and on safety — score 0 ... 1;

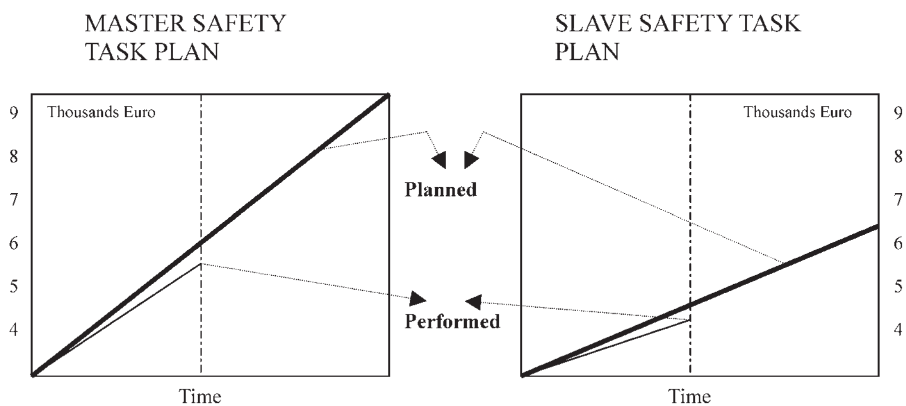

Figure 4. SAE example

Table 1. Example for SAE

No.	Workplace	Variance between planned and performed (expressed in thousands Euro)	Score	Observations
1	Preparation	−5	4	The lower value was given because actually the performed costs were higher than the planned ones
2	Pre-heating	20	3	Variance affects general performance but not safety
3	Process unit 1	100	1	Variance affects safety through the not performed tasks
4	Secondary heating	30	2	Variance affects safety through the not performed tasks
5	Transformation unit 1	0	5	The optimal situation in which the planned and the performed are the same
6	Final package unit	0.5	5	A near optimal situation

Table 1 presents an example regarding benchmarking with the analysis of variance for various workplaces in the above mentioned facility.

The analysis of variance computes the SSTP with the values of MSTP in order to obtain an optimal judgement.

This table shows that for two units (workplaces) inside our chemical facility the SSTP is almost unperformed — this aspect could seriously affect the safety of workers. For three workplaces the variance is nil or not significant; for a workplace the variance affects just the general performance through the need to re-locate the resources (materials, maintenance team) but is not affecting safety[7].

WORKPLACE SAFETY BENCHMARKING

In using SEV for benchmarking specific safety aspects at workplace we are taking into account two categories of elements that are inter-acting:

- safety actors (SA) — including tools, devices, locations, generally all non-human elements existent at the workplace;
- safety promoters (SP) — human operators that are directly participating at safety assurance at the workplace or are somehow affected by this safety;

SP could be in one of the three situations:

- gives safety — through its actions he/she contributes to the growth of SEV at the workplace;
- gets safety — SP is obtaining safety from an external source (for example participates at a safety training) or is getting safety devices from an external safety supplier, etc.;
- looses safety — SP is loosing safety through various processes like erroneous actions, forgetting, etc.

SA could be in one of the two situations:

- gets safety — from the direct or indirect activity of SP;
- looses safety — through decay, malfunctioning, etc.

Relations between SP and SA are shown in the Figure 5.

Safety costs are expressing the forecasted safety state of a usual action performed at the workplace through possible safety looses and gains Actually; safety costs for specific actions are computed taking into account:

- safety assessments;
- actual operational performance;

Safety costs are linked directly with actions performed at the workplace[8].

Generally, in using SEV at workplace we are using milestones, considering the following aspects:

- SA is affected by changes that could be clearly and well defined;
- SP is affected by events that could be clearly and well defined;

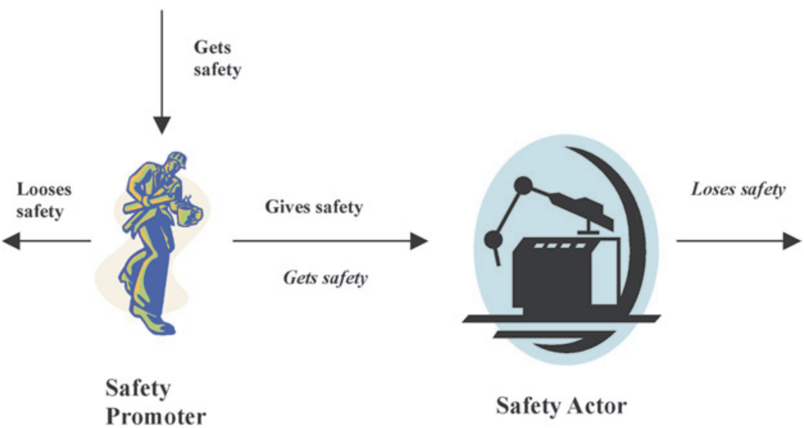

Figure 5. Relations between SP and SA

- Each milestone is owned by the Safety Responsible;
- There are clear and objective criteria for measuring accomplishments that could be mostly quantified;
- These criteria are directly related to safety assurance;
- Each milestone is weighted in relationship to safety resources;
- Each milestone is scheduled and related to MSTP and SSTP.

The milestones linked directly to the implementation of the safety plan are presented in Figure 6.

Safety Earned Value (SEV) is based on Earned Value Analysis (EVA)[9]. Actually, this is a way to measure the amount of safety performed on a project and to forecast

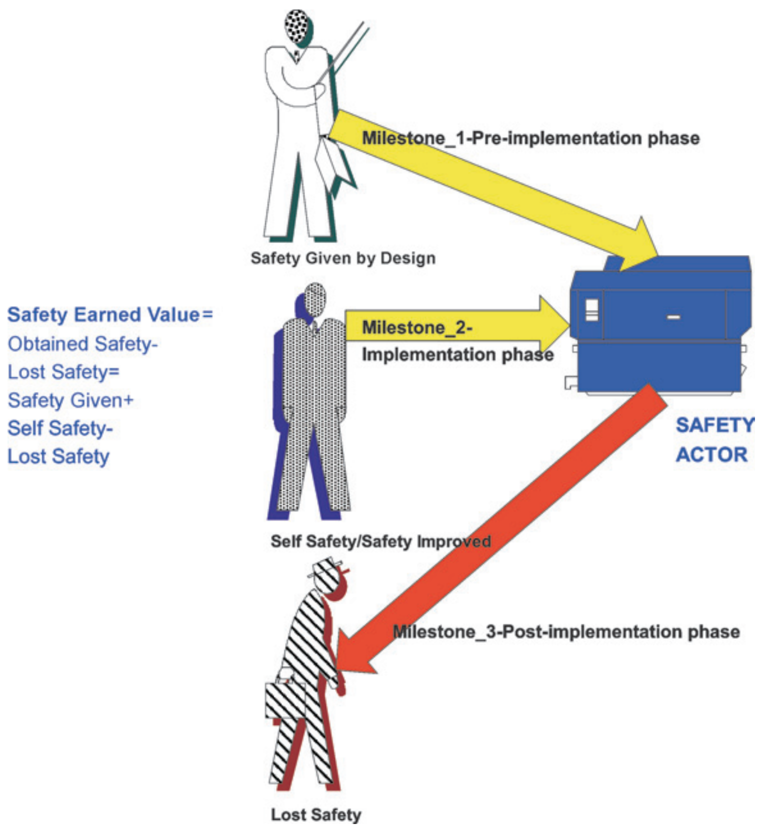

Figure 6. Main milestones for the safety plan

the safety costs. The method relies on a key measure known as earned value. The difference between the expected safety and the actual safety gives the safety schedule variance[10]. This variance could be the essential benchmarking parameter regardless of the type of activity being done. This measure allows computing performance indices in order to forecast future safety.

The essential safety earned value parameters are:

– Budgeted safety cost of work performed (BSCWP) — answers the question "How much safety has actually been completed?"[11]
– Budgeted safety cost of work scheduled (BSCWS) — answers the question "How much safety should be completed to this date?"
– Actual safety cost of work performed (ASCWP) — answers the question "How much safety we actually spent/gained performing the activity?"

From these values we could compute specific safety metrics like:

Safety Schedule Variance (SSV)[12]

$$SSV = BSCWP - BSCWS \tag{1}$$

If:

- $SSV = 0$ — safety is on schedule;
- $SSV < 0$ — safety is behind the schedule;
- $SSV > 0$ — safety is ahead of the schedule — ideal case

Safety Schedule Performance Index (SSPI)

$$SSPI = BSCWP/BSCWS \tag{2}$$

Safety Cost Variance (SCV)

$$SCV = BSCWP - ASCWP \tag{3}$$

Significant variance means that the original safety plan was not good; the management is informed that something needs to be examined, analyzed and proper corrective actions adopted.

Safety Cost Performance Index (SCPI)

$$SCPI = BSCWP/ASCWP \tag{4}$$

We will illustrate the usage of these metrics with two case studies:

CASE STUDY 1

This case study takes into account two chemical similar facilities A and B. A current activity in these facilities is the periodic change of a boiler used in a primary process. This change is performed by a maintenance team of three workers in both facilities. For the first facility, the maintenance team is composed by workers with similar qualifications. For the second team there is a highly qualified worker and two low qualified workers. To simplify the case all parameters are expressed on a 0 . . . 5 scale.

The following table gives our three main parameters together with the computed values.

Analysing the Safety Schedule Variance (SSV) we could see that each unit is behind schedule. However, the first unit is more close to the schedule than the second unit.

Also, the Safety Schedule Performance Index (SSPI) shows the lag behind the schedule.

Analysing the Safety Cost Variance we could see that every unit is under budget. However, by analysing the Safety Cost Performance Index we could see that the second unit is performing more economically.

Analysing the global values we could see that the first unit performs more optimally from the safety point of view. However, by reporting safety at actual costs the second team is more efficient.

Figure 7 is presenting all these aspects.

CASE STUDY 2

A foreign investor studies three possible investments in three units — two from the chemical industry and one from the extractive industry. One of his criteria is to safety benchmark the central production process of every unit in order to be able to make a

Table 2. Case study 1 summary

Parameter	Chemical Facility 1	Chemical Facility 2
Estimated parameters		
BSCWP	3	2
BSCWS	4	4
ASCWP	2	1
Computed parameters		
SSV	−1	−2
SSPI	3/4	2/4
SCV	1	1
SCPI	3/2	2

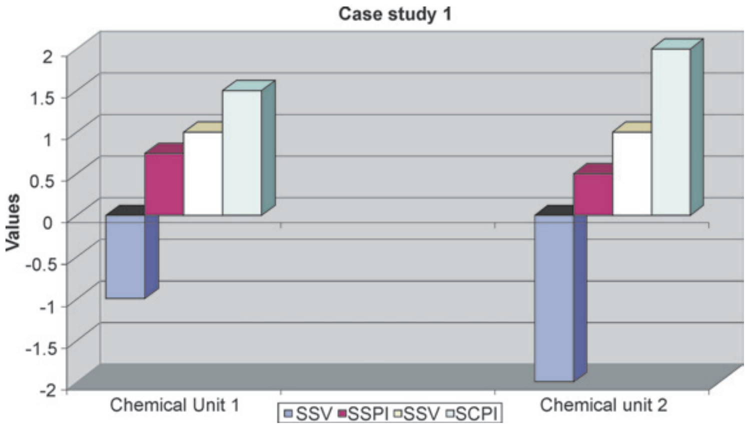

Figure 7. Case study 1

valuable judgement. In taking this approach he had performed a safety audit of each unit and also had established that generally the workers are mid-level trained and also the safety technique at workplace is satisfactory for every unit. The table below presents the results:

The third unit performs most safely efficient. Figure 8 gives the results graphically.

THE BENCHMARK PACKAGE

Our benchmark system is designed to check safety performance versus operational performance, taking into account also statistical indicators as the Figure 8 shows.

Table 3. Case study 2 summary

Parameter	Unit 1 (Chemical)	Unit 2 (Extractive)	Unit 3 (Chemical)
Estimated parameters			
BSCWP	5	3	4
BSCWS	3	4	1
ASCWP	5	5	3
Computed parameters			
SSV	2	−1	3
SSPI	5/3	3/4	4
SCV	0	−2	1
SCPI	1	3/5	4/3

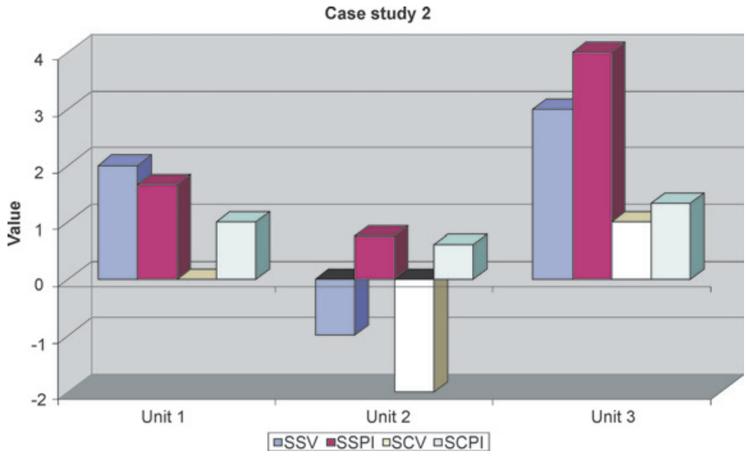

Figure 8. Case study 2

Figure 9. Safety benchmarking package main criteria

FROM QUALITY OF SAFETY PLANS TO GLOBAL QUALITY OF SAFETY

Quality of Safety Plans is given by a number of factors. These factors are heavily dependent on:

- the design team[13]
- the optimal analysis of the safety situation[14] at the workplace (before the implementation of the plan)
- the study of the four elements of the man — machine system and their interaction;
- the available implementation resources;
- the active involvement of workplace team in the implementation and execution of the plan;
- management and safety culture at the implementation place[15];

Figure 10 shows these aspects.

To be adequate, the analysis of safety plan's quality must be performed:

– in the pre-implementation phase in which is investigated the design of the plan;
– in the post-implementation phase in which are investigated the obtained results[16]

Figure 11 shows these aspects.

The most important factors for the pre-implementation quality analysis, together with their importance coefficients are presented in Table 4.

The coefficients were established empirically considering a number of 300 case studies performed in the 1980–2000 period.

The pre-implementation quality index of the safety plan could be computed as

$$\text{QISP} = \frac{\sum Qc}{nC} \tag{5}$$

where Qc are Quality coefficients and nC is the number of considered coefficients.

The most significant factors for the post-implementation analysis[17] are summarized in the table below:

The quality post-implementation coefficients were established after an analysis of 150 safety plans implementations in various units mainly from chemical industry. A case study is presented below.

CASE STUDY 3

A network of gas stations was implementing a safety plan for its 50 stations in Romania. The safety plan was designed by a team composed of Romanian and foreign experts — the mother company being Austrian.

The pre-implementation analysis was performed using the following main factors:

$$\text{QISP}_{\text{pre}} = (0.7 + 1.1 + 1 + 0.3 + 1.1 + 0.7)/5 = 0.98$$

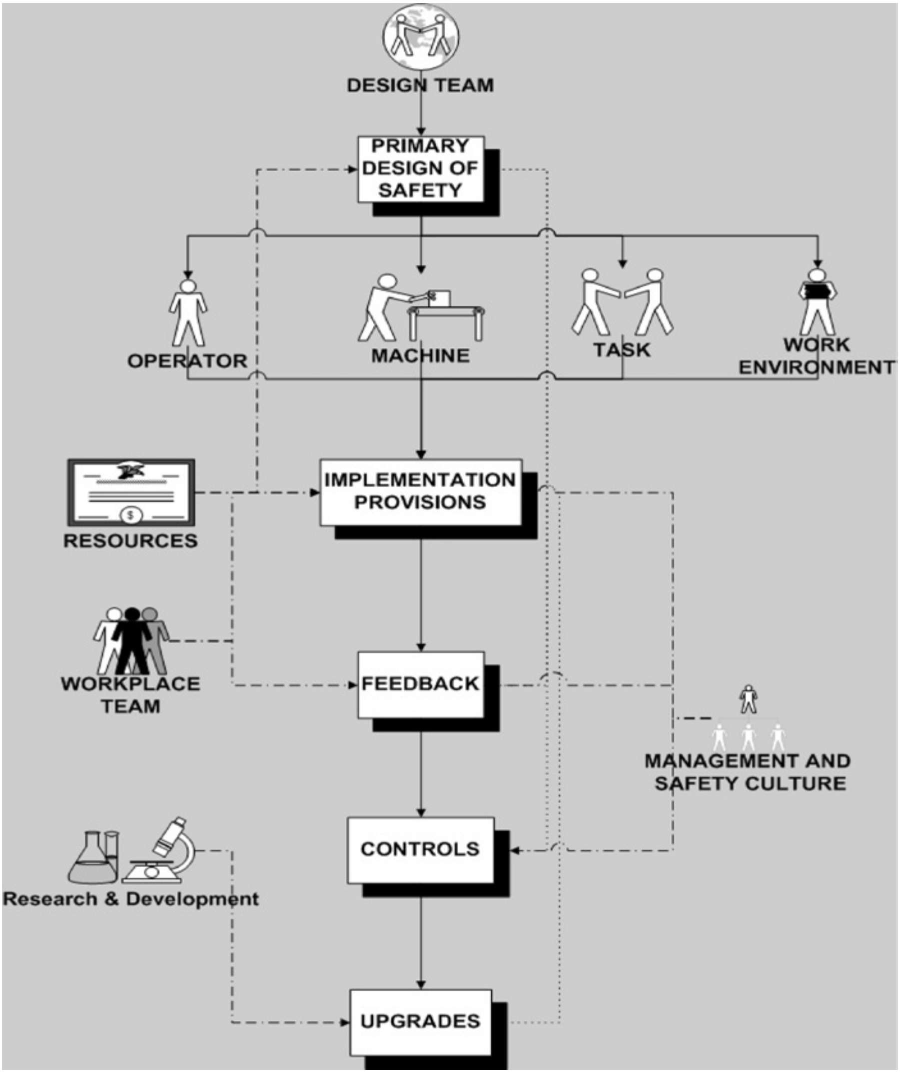

Figure 10. Specific factors for the quality of safety plans

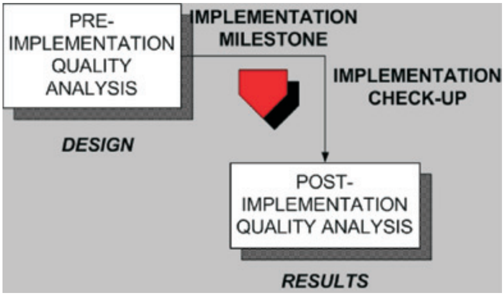

Figure 11. Steps in the quality analysis of safety plans

Table 4. Pre-implementation factors and their importance coefficients

Quality pre-implementation factor	Quality importance coefficient (Qc)
Design Team	0 . . . 0.8
Designed safety quality for workplace components and interactions	0 . . . 1.7
Designed safety plan implementation provisions	0 . . . 1.2
Designed safety plan feedback	0 . . . 0.3
Designed safety plan controls	0 . . . 1.1
Designed safety plan upgrades	0 . . . 0.9

Table 5. Post-implementation factors and their importance coefficients

Quality post-implementation factor	Quality importance coefficient (Qc)
Control of unexpected events	0 . . . 1.5
Loss reduction	0 . . . 1
Optimisation of safety resources	0 . . . 0.5

So, it could be considered that the quality of the design of safety plan (in the pre-implementation analysis) is 98%. As a pre-implementation quality of 100% is ideal it could be considered that this quality is excellent.

A post-implementation analysis of the safety plan quality was performed after two years, considering as a reference the period of two years before the implementation.

$$QISP_{post} = (0.7 + 0.9 + 0.5)/3 = 0.7$$

Table 6. Case study pre-implementation summary

Quality pre-implementation factor	Quality coefficient	Comments
Design Team	0.7	A joint Romanian and foreign safety expert's team. All the experts had more than 10 years of expertise in the safety field. The basis of the safety plan was built using safety frames from the mother company.
Safety quality for workplace components and interactions	1.1	The coefficient was established considering the real safety conditions that could be assured by the safety plan.
Safety plan implementation provisions	1	The implementation provisions were designed considering the joint implementation possibilities.
Safety plan feedback	0.3	The feedback was developed in order to obtain the maximum response from the workplace teams.
Safety plan controls	1.1	There were provided efficient controls for the safety plans.
Safety plan upgrades	0.7	There were provided two upgrades, after each period of two years.

Table 7. Case study post-implementation summary

Quality post-implementation factor	Quality coefficient	Comments
Control of unexpected events	0.7	After the implementation of the safety plan there was a sharp reduction in the number of unexpected events; however, this reduction was not as expected. A near miss event (in which the unexpected open flame in the nearby of a gas station was close to blow up the station) appeared in this period as the most serious event.
Loss reduction	0.9	Loss reduction was in the expected range.
Optimisation of safety resources	0.5	Optimisation of safety resources was maximal.

Table 8. Coefficients for the global safety quality benchmarking formula

Quality Factor		Coefficients
Quality of design	QD	k1 = 0,135
Quality of logistics	QL	k2 = 0,12
Quality of human factors[20]	QHF	k3 = 0,125
Quality of existing safety at the workplace	QES	k4 = 0,09
Quality of implementation	QI	k5 = 0,145
Quality of participation[21]	QP	k6 = 0,11
Quality of controls	QC	k7 = 0,15
Quality of upgrades and feedback	QUF	k8 = 0,125

So, after two years of the safety plan, the perceived quality could be estimated to be 70%.

The difference between the expected quality of the safety plan and the real quality could be justified by the low involvement of the local management of the gas stations which was directly involved in the control of unexpected events.

An empirical global safety quality benchmarking formula could be used when there is no need for pre and post implementation analysis[18]. This formula is given below together with its coefficients.

$$\begin{aligned} \textit{Quality of safety} = (&k1^{*}\text{Quality of design} + k2^{*}\text{Quality of logistics} \\ &+ k3^{*}\text{Quality of human factors} \\ &+ k4^{*}\text{Quality of existing safety at the workplace} \\ &+ k5^{*}\text{Quality of implementation} \\ &+ k6^{*}\text{Quality of participation} \\ &+ k7^{*}\text{Quality of controls} \\ &+ k8^{*}\text{Quality of upgrades and feedback})/8 \end{aligned} \tag{6}$$

The values of coefficients k1 ... k8 are presented in the next table[19]

CONCLUSIONS

Transition towards a market economy has left its imprints also on the ways to perform safety. The more safety prone units had a good future; the less safe ones are leaving from the market. This process is an irreversible one — however, in order to decide which enterprise performs more economically and also more safely a safety benchmark system is needed.

Such a system is presented in this paper. In starting our research we sought to find similar systems on the market, in the idea to be able to adapt an existing system to our safety needs. The documentation regarding such systems was not available so we have developed such a system for ourselves. Our system is fully functional.

The developed system is a modular one. Specific modules could be added for all the components of man – machine system, essentially for the man and machine components.

The developed system takes into account the possible lag between human aspects assessment and machine assessment. Generally, its structure allows an objectivity degree up to 95%. Biasing factors were eliminated in order to perform as objective as possible. Here, the expert systems approach, using fuzzy uncertainty coefficients was very helpful.[22]

Our system is an open one. New structures could be added in order to have a more global safety view. Generally, the system was developed in order to benchmark units from the same industry. However, the system could be used to benchmark units from different industries – in order to establish more innovative ideas to perform more safely at the workplace.

The computerised approach allows the efficient performance of the benchmark process. Using networks the system could process two or more units in the same time so that the benchmark speed is optimal.

Our system is not perfect – it is perfectible. Its open structure allows the dynamic updating with the latest safety benchmarking modules.

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