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A Multidimensional Approach to Modelling for Workplace Risk Assessment

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This paper aims to help enhance the process of risk identification and assessment in small enterprises by facilitating the incorporation of insights from accident, human error and risk perception models. This effort takes place through grouping and classification models of all these aspects according to certain criteria, to fit the proper set of models to each situation. To further facilitate the process, the main guidelines of each model are presented. The whole approach is not a new theoretical model but a simplified presentation to help safety engineers in selecting the proper model for the workplace to better assess its risks. An example of the application of this approach is also presented.

human error risk perception accident models risk assessment

1. INTRODUCTION

The first step for the proper handling of workplace risk is an effective assessment. This process involves two components:

- a model, i.e., an intuitive understanding of the tasks, the system (by means of sociotechnical factors) and the factors that may lead to an accident;
- a method, i.e., a structured framework (e.g., a standard) for the analysis of actions and materials that assures a systematic examination of the hazards.

Thorough risk assessment is conducted in the context of a certain method, reflecting, however, the underlying model of the analyst, which is the situation-specific component of risk assessment. This paper focuses on the modelling of workplace risk aiming to facilitate safety engineers in the selection of the proper model for each situation.

Workplace risk modelling has been examined from different points of view and through different scientific disciplines. The fact that human action along with materials and procedures interact in a complex system has allowed approaches both from engineering and social sciences to develop conceptual models describing the way in which an accident occurs. In general, the study of workplace accident risks has been developed along three dimensions of research:

- accident models: mainly based on systems study, a number of models describes causal mechanisms that lead to an accident;
- human error/factors/reliability: variability of human performance is examined as the main cause of accidents;
- risk perception/communication: this point of view examines human perception of risk, the consequent behaviour and its relation to accidents.

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All these aspects can contribute to the completeness of the assessment of workplace risk, which is the basic tool for its management. This completeness becomes even more necessary in the modern work environment, whose main features are

- an increase in small enterprises (SEs); between 1988 and 2003, the number of and employment in SEs saw a significant increase [1, 2]. A wide literature (cited in Sørensen, Hasle and Bach [3] and Dorman [4]) indicates higher accident risk and incidence rates in such enterprises, especially for serious injuries [5, 6];
- flexible employment: precarious employment saw a significant increase during the past decade [2, 7]. In general, there is evidence that accident risk is systematically higher for temporary employees [7, 8, 9] and self-employed persons [7]. Concerns are also raised for part-time workers and employment through agencies;
- advanced technology: it is widely accepted that new technology brings advanced safety standards, although there is literature [2, 10, 11, 12] stating that it increases complexity (especially when it comes to "lean" production), thus increasing other forms of risk.

Since an increasing proportion of workers is employed under such conditions of higher risk, risk assessment has to adjust to the characteristics of these conditions. Some important implications of the new working environment on workplace risk are

- stress: new contractual forms of employment [2, 7, 8, 9], insecure prospects of SEs, and lean production [12] increase job insecurity and stress;
- cognitive limitations: precarious or immigrant workers, as well as workers in SEs are less likely to have adequate training and experience. Such a workforce, in a working environment of complex hi-tech equipment and lean production is less likely to have cognitive control over their tasks;
- risk taking: numerous studies (cited in Harrisson and Legendre [10]) support a positive relation between precarious employment and risky behaviour.

These implications indicate that the Tailoristic model of workers without economic motive for taking risks and with absolute control over their actions is no longer efficient in the assessment of occupational risks. Intentional behaviour (i.e., concessions) of workers against risk has to be seriously taken into account. This is also the case for unintentional individual impact (human error), since stress and cognitive limitations, along with complexity, are important factors for erroneous behaviour.

However, incorporation of system complexity effects, human factors and risk perception is not easy, especially for a technically-oriented safety engineer with limited time (particularly in an SE), who generally follows the selected risk assessment method mechanistically, without an explicit situation-specific model. This implies Tailoristic assumptions that are no longer valid in a modern workplace. In this paper it is attempted to facilitate the incorporation of all these factors into risk assessment by presenting a simple demonstration of the existing models of all dimensions and a structure that facilitates the selection of the proper model for each situation.

2. METHODOLOGY

To obtain this goal, existing models of all three dimensions of workplace risk research are grouped into categories and classes according to certain criteria, to facilitate the selection of the proper set of guidelines—models for each situation depending on its characteristics. In terms of safety, the most important characteristic of a system is complexity, which is usually described by coupling[1] [13], control [12], and the multitude of potential paths/outcomes [14], or respectively autonomy, feedback and variety/identity [15]. Thus, the criteria for model selection have to be related to these factors. More specifically, these criteria are

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[1] Perrow (1984) as cited in Bellamy and Greyer [13].

- degrees of freedom: the number of factors that can alter the state of the system and consequently the multitude of alternative states (paths, outcomes) where the system can be found. For example, driving a train has only one degree of freedom (adjustment of speed), whereas flying an aeroplane has many degrees of freedom (attitude, speed, air lane, etc.);
- controllability: the extent to which the examined individual (e.g., operator) exerts control over the process (simplicity, direct feedback, etc.) For example, a car driver can have full control of the car, whereas a doctor does not have full control of a patient's health;
- context impact: the extent to which the state of the system depends on external (contextual) factors (e.g., autonomy or coupling). For example, in terms of safety, the work of a car mechanic is independent of the context compared to the work of a roadside construction worker.

There is no priority among these criteria, since different criteria may be more relevant in different situations. Therefore, any criterion might be the dominant one for the selection. Systems with many degrees of freedom, low controllability and significant context impact (more complex) require (sophisticated) models with respective features. These models would also apply to simpler systems but this would add unnecessary and unaffordable complexity. Other criteria (such as level of decision-making, level of analysis required, individual or team context, etc.) might also be taken into account for the selection of the proper model.

Of course, the advantage of a simple and yet multidisciplinary approach has a cost for the scientific precision and theoretical accuracy. Moreover, characterization of a system or of a model according to these criteria involves a degree of subjectivity. Consequently, a holistic objective classification of models is not possible. Nevertheless, this approach only aims to be a practical way to incorporate all aspects of the system into the model that the safety engineer develops to help assessment of risks in SEs, rather than being the new integrated theory for safety.

3. MODELS

In the following sections, models of each dimension of research are briefly presented to be grouped and classified according to their characteristics. To be concise, the models are simplified to certain guidelines.

3.1. Accident Models

A first set of accident models includes those that follow the sequential paradigm, i.e., the accident is a result of discrete successive events that occur shortly before the incident to lead sequentially to it, according to the domino metaphor. These models assume direct and explicit feedback and thus can only be applied where controllability is high.

The hazard-carrier model[2] sees the accident as a physical collision of individuals against their environment. Application of this model involves analysis of all possible human body movements during the task and identification of the risky ones. This model is very analytical; therefore, (due to the great variability of human movement) it can only be used where degrees of freedom are few so that the scope remains reasonable.

Sequence-based models (Royal Society for the Prevention of Accidents, RoSPA[3]; Information System on Occupational Injuries, ISA[4]; Kjellén's[5]; and MacDonald's[6]) see accidents as a sequence of successive events that can be combinationally described as normal situation–pre-events–loss of control–breakout–injury; therefore, potential relevant events are examined in this framework, whereas the steps forwards or backwards in a causal chain are analysed to identify the main drivers and influences. The scope of the analysis

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[2] Skiba (1973) as cited in Kjellén and Larsson [20].
[3] Manning (1974) as cited in Kjellén and Larsson [20].
[4] Lagerlöf and Andersson (1979) as cited in Kjellén and Larsson [20].
[5] Kjellén (1983) as cited in Lees [16].
[6] MacDonald (1972) as cited in Lees [16].

is much more concise in this case; therefore, it can be applied along many degrees of freedom. Situations of high context impact are not incompatible with this approach.

The Svenson model [18] also belongs to this category but it differs in its approach, since it sees the accident as the end of a sequence of preventive measures that failed. Therefore, it can be applied in similar systems but where preventive measures are the main parameter. All preventive measures are written down and their failure scenarios are analysed focusing on the likelihood of simultaneous failure.

Event Tree Analysis (ETA) is a special case of sequential models that can also model systems with many degrees of freedom, but only subject to the assumption of mutually exclusive events and independent sequences that are analysed in a tree-shape scheme. Context impact is not explicitly taken into account; therefore, it has to be low.

A second set of accident models (fully or partly following the epidemiologic or the systemic approach) also takes system factors into account in the etiology of the accident (e.g., latent failures, complex interactions) These models can be applied in situations where controllability is low (a system is too complex to control).

Coincidence-based models (Houston[7]; Trigger Coupling Model, TCM [19]; and Management Oversight Risk Tree, MORT[8]) see the accident as a conjunction of target, driving force/energy flow and trigger, with parallel preventive or adaptive action (defenses). All elements (target, driving force/energy flow and trigger) have to be identified and analysed along with parallel factors (preventive–corrective action, management). These factors help incorporate context impact (e.g., management), but their analysis is deep and extended, which limits its application to systems with rather few degrees of freedom to be concise.

Variability-based models (Institut National de Recherche et de Sécurité, INRS[9]; Occupational Accident Research Unit, OARU [20]; and Causal Tree Method, CTM[10]) see the accident as a result of a series of events in the form of deviations from the expected work circle. Their application involves an analysis of the variability of each element of the expected work circle and of the potential results to the final state of the system. Their deep analysis (e.g., sensitivity analysis by studying the interactions of each fluctuation) limits the feasible degrees of freedom (i.e., the number of elements in the sequence that may vary) to keep a reasonable scope. For the same reason it is recommended to be applied in systems of low context impact (the study of internal variability alone is enough).

The Markov method[11] identifies all possible states of the system and the rate of change between these states. Its application involves in-depth analysis of all potential situations of the system; thus only few degrees of freedom (i.e., few alternative states) are feasible in a reasonable scope. However, since the focus is on states of system rather than sequential events, this approach can be applied in systems with important context impact.

Epidemiologic approach models (Advisory Committee on the Safety of Nuclear Installations, ACSNI[12]; International Safety Rating System, ISRS [22]; and Assessment of Safety Significant Event Teams, ASSET[13]) that examine latent and managerial weaknesses as causes of accidents and systemic models (Systems Theory Accident Modeling and Processes, STAMP [12]) where focus is on different sociotechnical levels of control and constraints of safety-related behaviour at each level, are sophisticated models that are only indicatively mentioned, since they would hardly apply to an SE.

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[7] Houston (1971) as cited in Lees [16].
[8] Johnson (1980) as cited in Livingston, Jackson and Priestley [17].
[9] Monteau (1977) as cited in Kjellén and Larsson [20].
[10] Leplat (1978) as cited in Kjellén and Larsson [20].
[11] Billinton and Alan (1983) as cited in Sun and Andrews [21].
[12] Advisory Committee for Safety in Nuclear Installations (1991) as cited in Lees [16].
[13] International Atomic Energy Agency (1991) as cited in Lees [16].

3.2. Human Error Models

The recovery model sees human error as a function of time available for recovery (from the unavoidable initial deviation). According to this approach focus should be set on the recovery effort of the individual, which might even deteriorate the situation. Therefore, potential recovery routines and actions should be examined along with the likelihood and results of incomplete execution. Typical errors include incomplete recovery (insufficient time), inefficient diagnosis and selection of wrong recovery routine. It can only be applied where the individual has full control over the task process and direct feedback information, so as to be able to perform corrections (high controllability). Recovery action at low level of decision-making may only apply when degrees of freedom are few (within a worker's span of control). Context impact (externally caused interference) cannot be incorporated in that simple self-correcting loop.

Information processing model sees error probability as a function of individual mental load, thus presupposing individual task controllability as all causes of error lie within the individual's mind. Context impact is indirectly taken into account (adding to mental load). The model applies only to systems with few degrees of freedom as the analysis of the impact of many parameters in the mental load is practically impossible. It better applies when stress is a key parameter in the system. Some possible errors include [23]

- omission, if the priority is to undisturbedly continue an on-going process;
- reduced accuracy, if the priority is to reduce time;
- queuing, if the priority is not to lose any information;
- omission of some categories, if there are intense limitations of space/time;
- cutting categories, if the priority is to avoid large fluctuations;
- tendency to adhere to practical routines that legitimate the decision-maker, in situations of increased stress [24];
- "involuntary rest"[14], i.e., the repetition of the same sequence of stimuli–reply leads to a neuric state of quasifatigue that requires rest, during which no attention is paid to the task.

Cognitive models (Skill–Rule–Knowledge, SRK[15]; Reason's Absentmindedness model [25]; Systematic Human Action Reliability Procedure, SHARP[16]; and Task Analysis-Linked Evaluation Technique, TALENT [26]) distinguish different levels of decision-making and examine the behaviour (and sorts of error) in each of these levels.

According to this approach, in the low level of decision-making typical errors (slips and lapses [27]) include

- transition from one routine to another more frequent one during a common stage of the two routines, especially when the individual is busy with other thoughts;
- omission or double execution of a stage after an interruption;
- errors in execution due to the control process of the task;
- gradual omission of steps perceived as safe or unnecessary.

In medium level of decision-making, typical errors (mistakes of rules [27]) involve wrong diagnosis, confusion of alternatives (up-down, right-left, etc.) and memory failure or tendency to adhere to usual guidelines even when they are no longer valid. In higher level of decision-making, errors (mistakes of knowledge [27]) mainly involve inadequate understanding or knowledge of the situation.

A common tendency in all levels is to gradually bring decision-making to lower levels. Errors of lower levels are also present in higher levels of decision-making: slips in the stage of execution, lapses in the stage of storage and mistakes in the stage of planning. The examination of different

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[14] Fine (1963) as cited in Kjellén and Larsson [20].

[15] Rasmussen (1983) as cited in Lees [16].

[16] Hannaman and Spurgin (1984) as cited in Cacciabue [32].

levels of decision-making separately, limits the scope (analysis takes place only in the relevant levels) thus making them proper for tasks of many degrees of freedom. No specific limitations appear for controllability and context impact.

The sociotechnical models are more proper for situations of higher context impact due to their social component, whereas the dependence on group behaviour inevitably limits the application to cases of low individual controllability. Group dependence is translated into high context impact. Two important sources of errors according to these models are [28]

- "team thinking", when people adopt someone else's erroneous judgement without much thought (e.g., due to trust), so that the error is repeated or transferred uncorrected through next stages;
- "dependence", when actions perceived as independent are not truly so, such as common cause errors due to hidden common initial conditions (e.g., inadequate training or design processes) and human caused dependence (e.g., one inefficient technician making the same mistake in many systems).

Quantifiable models (Time Reliability Correlation, TRC[17]; Technique for Human Error Rate Prediction, THERP[18]; and Human Cognitive Reliability, HCR[19]), contextual-ergonomic models (Success Likelihood Index Method, SLIM[20]; and Human Error Assessment and Reduction Technique, HEART[21]) and "second generation" models (Information–Decision–Action–Crew, IDAC [31]; Human Error Risk Management for Engineering Systems, HERMES [32]; Cognitive Reliability Error Analysis Method, CREAM [33]; and A Technique for Human Error Analysis, ATHEANA[22]) are only indicatively mentioned for use in more complex systems, since their application requires too much effort and expertise for an SE.

3.3. Risk Perception

A first category of models assumes that perception of risk and decision-making takes place at the individual level. Such models are meaningful only in situations where degrees of freedom are only few (within the immediate span of individual control) so that the individual can comprehend and adjust the parameters.

According to the approach of contingencies, individuals keep acting in ways that were rewarded before. This approach presupposes absolute and immediate control of the individual (decision-making) of the task, since the adjustment based on the feedback is immediate. There are no provisions for context impact, since the correction procedure is a closed loop. The analysis focuses on the potential outcomes of the feedback process in the repetition of the task.

The Risk Homeostasis Theory (RHT) [35] supports that individuals try to maintain a constant level of risk that (according to them) optimises the balance of benefits and potential losses of the risky choice. This model also applies only in cases of increased controllability and direct feedback, so that the individual is able to immediately comprehend the level of risk and adjust it. The analysis takes place in an absolutely individual level (low context impact–closed loop) trying to identify the counteracting threats and the potential level of performance where they are balanced.

The notion of selection between perceived benefits and losses is also common in the framing-effect approaches (e.g., Prospect Theory [36]). According to them, individuals make certain choices of risk against the secure choice depending on their feelings for the situation as it is presented (framed). Like RHT, analysis is on individual level and it includes identification of potential emotional influences that might affect the behaviour of individuals (e.g., the balance of perceived threats described by RHT). Controllability is also increased, since only the

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[17] Hall, Wreathall and Fragola (1982) as cited in Jo and Park [29].
[18] Swain and Guttann (1983) as cited in Cacciabue [32].
[19] Hannaman, Spurgin and Lukic (1984) as cited in Mosleh and Chang [31].
[20] Embrey, Humphreys, Rosa, Kirwan and Rea (1984) as cited in Mosleh and Chang [31].
[21] Williams (1986) as cited in Lydell [30].
[22] Cooper, Ramey-Smith, Wreathall, Parry, Bley, Luckas, et al. (1996) as cited in Pyy [34].

individual is taken into account in decision-making; however, the influence of context impact is important in presentation (framing) of risk, which is here subjective and context-dependent. Some insight of these approaches include

- people tend to be risk-averse when they perceive opprtunities and risk-prone when perceiving threats [36];
- in case of positive mood (e.g., after successful performance) people tend to be risk-averse, whereas in case of negative mood, people tend to be risk-prone to gain benefits that will change this mood [37];
- anger leads to risk-proneness, whereas fear leads to risk-aversion [38];
- stress increases risk-proneness [39];
- sorrow leads to risk-aversion [39];
- calmness leads to risk-aversion [39].

The balance of perceived gains and losses also prevails in value expectancy models (Theory of Reasoned Action[23], Health Belief Model[24], Theory of Planned Behavior[25] and Protection Motivation Theory[26]), where individuals choose their course of action in accordance to a balance of (perceived) potential gains and losses, which might also include [40]

- attitudes, i.e., the psychological assessment of a behaviour (good, bad, etc.);
- subjective norms, i.e., the attitudes of other individuals, whose opinion is highly appreciated;
- feeling of vulnerability, i.e., the extent individuals can imagine themselves as potential victims (e.g., possibility of experience in themselves or familiar persons);
- perceived control on the task execution (and its risks);
- perceived constraints in following preventive measures;
- perceived benefits of safe behaviour.

The existence and magnitude of these elements has to be explored and added as a potential influence. Decision-making is still at the individual level, where all the relevant factors are focused, without provisions for explicit influence of the context. However, this model can apply where controllability is low (indirect perception of the situation) as the feedback loop is not direct, due to the impact of a number of subjective factors.

The psychometric approach[27] stresses that the behaviour of an individual against risk is determined by what is perceived to be the case rather than by what is the case. This perception is defined mainly by personal feelings, such as

- fear, i.e., the subjective impact of the severity of the consequences of an accident (e.g., likelihood of a tragic death is feared more than likelihood of a more usual death);
- uncertainty, i.e., the extent to which there is (reliable) information for the likelihood of an accident;
- trust, i.e., the extent to which the individual trusts the source of information for the risks and the safe behaviour;
- perception of interests, i.e., biases in perception of risks depending on the perception of who benefs from exposure;
- voluntariness, i.e., greater acceptance of risks, exposure to which is voluntary and not imposed;
- familiarity, i.e., the extent to which the risk is perceived as known (and potentially controllable).

Like in value expectancy models, the influence of these feelings should be examined. Likewise, this approach is more proper for situations where individuals have limited control on the task (interference of subjective factors in the feedback loop); however, it can also apply to situations with higher context impact, since the factors examined by this approach are more context-dependent.

A second category of models includes those that assume perception of risk in a social level (or with strong social influence), either the decision lies at the individual or in group level. In these

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[23] Fishbein and Ajzen (1975) as cited in Weyman and Kelly [40].
[24] Janz and Becker (1984) as cited in Weyman and Kelly [40].
[25] Ajzen (1991) as cited in Weyman and Kelly [40].
[26] Rogers (1983) as cited in DeJoy [41].
[27] Fischhoff (1978) as cited in Weyman and Kelly [40].

cases, decisions are not based on an explicit one-dimensional feedback loop; therefore, they can be applied in systems with more degrees of freedom.

The sociotechnical approach appears to be the most proper where risk is dealt with at a group level; the impact of external (contextual) factors is either high or low. Various guidelines can be found in literature that can be relevant depending on the situation:

- leadership effect, i.e., people are more likely to follow safety measures if they perceive high commitment of top management towards them;
- risk-prone members of a team are those that are more likely to take initiatives;
- the attitude of the best established (representative) members of a team is more likely to define the behaviour of the whole team;
- isomorphism, i.e., individuals balance between competition (for profit maximisation) and team legitimisation, the latter being more dominant in coherent teams;
- new members of a team are more likely to follow risky behaviour if they perceive that the team is risk-prone;
- group polarisation, i.e., after becoming members of a team, individuals' attitudes converge to the average attitudes of the team;
- obedience, i.e., convergence to common norms is stronger in medium-size, coherent and unanimous teams;
- team behaviour can only change slowly.

In mental models, risk is indirectly perceived through a set of heuristics (mental model) that depends on the social group where the individual is classified. Finally, in safety culture risk is met in an individual level but with an intense effect of institutional values embedded in the system. These approaches are only indicatively mentioned, since their applicability for an SE is doubtful.

4. STRUCTURE

We claim that an accident is a result of the impact of both the individual (voluntary and involuntary action, i.e., human error and risk perception respectively) and other elements of the system (accident models), such as materials, equipment, processes, installations, etc. Therefore, a combination of models of each dimension may provide a better insight for the identification and modeling of occupational risks. In sections 3.1., 3.2. and 3.3., models of each dimension of this conceptual model were simply presented to help safety engineers to gain more insight in risk assessment, without a prerequisite expertise in these topics. Moreover, to assist the selection of the proper model, these models have been indicatively grouped and classified according to three features (degrees of freedom, controllability and context impact) (Table 1).

It has to be emphasised that this picture is indicative. It is not a qualitative ranking or

TABLE 1. Classification of Models According to Criteria

Degrees of Freedom	Controllability	Context Impact	Accident Models	Human Error Models	Risk Perception Models
Few	high	high	hazard-carrier	information processing	framing effect
		low		recovery	RHT, contingencies
	low	high	coincidence-based, Markov	sociotechnical	psychometric
		low	variability	(second-generation)	value expectancy
Many	high	high	sequence-based, Svenson	cognitive, (quantifiable)	sociotechnical
		low	ETA	cognitive	
	low	high	(STAMP)	cognitive, (contextual)	(safety culture)
		low	(epidemiologic)	cognitive, (second-generation)	(mental models)

Notes. RHT—Risk Homeostasis Theory, ETA—Event Tree Analysis, STAMP—Systems Theory Accident Modeling and Processes.

grouping of models, but a practical classification, aiming to facilitate the selection of the simplest models that can provide a sufficient description of the situation in each case.

To illustrate the use of this structure and the selection of different models in different cases, some features of the modern work environment will be examined in an indicative example. These features are

- new forms of employment (self-employment/subcontracting);
- new trends in production (lean production: just-in-time)

To be concise, a task with few degrees of freedom will be examined. Suppose a worker has to do a simple task in an assembly line (e.g., welding). The worker might either be a full-time long-term employee on a fixed salary pay ("regular") or a subcontractor employed on a piece-rate payment (PRP) basis. The organisation may either be a modern lean organisation with a tightly coupled production without intermediate buffers or a traditional line with discrete independent work-posts and specialised (practically isolated) workers.

In the case of PRP, workers are free to work in any speed; however, the faster they work the more income they get (thick black dotted line in Figure 1). On the contrary, the regular worker has to meet a certain minimum accepted speed but will get no more income for working above this threshold (thick continuous line). Therefore, the PRP worker has more control of the situation.

Assuming that work speed is inherently fluctuating (say, a normal distribution with a mean equal to the target-speed like the thin grey line) and accident probability increases with speed (grey dotted line), the situation can be described as in Figure 1.

The only economic motive for the regular worker to work faster is the elimination of the probability of falling behind the threshold (grey area). However, the PRP worker has a continuous economic motive for working faster (and taking more risks).

In the case of a traditional loosely coupled production line, context impact is low, as people are practically isolated in their work. In such a line with the PRP worker, the proper set of models (see Table 1) is

- the hazard-carrier: since the worker is practically isolated and has a motive to go faster, an accident can come only as a result of his/her moves that have to be analysed (as either voluntary or not);
- recovery: the worker is isolated in a simple task without external interference; therefore, is trying to optimise performance by self-correcting errors. Figure 1 can be very helpful in this respect, if potential deviations are identified. If by mistake the worker goes to one edge of the speed curve, then he/she is expected to counteract by moving in the opposite edge of the curve;
- RHT, contingencies: the worker is in an isolated feedback loop with strong counterbalancing motives (income and risk) (Figure 1), given that a measure of the variability of speed curve is identified. The worker is expected to gradually find the optimum performance where risk and benefits

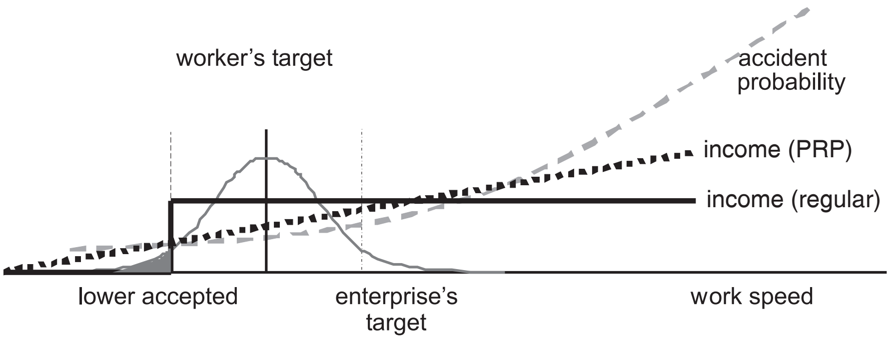

Figure 1. The balance of work speed for 2 different cases of labour. *Notes.* PRP—piece-rate payment.

are balanced. RHT would better fit if there was a minimum threshold of production speed required by the worker (so that the balance is between two counteracting risks).

If the PRP worker works in a tightly coupled production, apart from the hazard-carrier (as an accident model) the respective human error and risk perception models would be

- information processing: the mental load is higher, since the worker now has to always maintain minimum performance to keep up with the rest of the production line. Therefore, there are priorities that depend on the relation between rewards and risks. Thus the guidelines of this model apply rather than a strict optimisation of speed–risk equilibrium;
- framing effect: as a PRP worker, the worker will still be rather individualistic but more factors would enter in the trade-off, as his/her greater relation to the rest of the working context is more likely to lead in stress and other feelings that would bias decision-making.

In the case of the regular worker in the loosely coupled work environment, Table 1 indicates the following set of models:

- variability: since the worker is rather isolated with a simple task, he/she is mainly concerned about the possible variability of his/her performance (thin grey line in Figure 1), which is the only threat he/she faces;
- second-generation models: human error in this situation is less predictable; therefore, it should be dealt with by an advanced model (second-generation);
- value expectancy: the level of decision-making is still individual; however, workers have a number of factors to take into account, since their economic motive is not dominant, whereas a number of other factors (norms, attitudes, etc) are likely to enter the trade-off.

In the case of a tightly coupled production system, Table 1 suggests the following set of models:

- coincidence-based or Markov: the influence of external factors and management is very important due to the tight interactions and the absence of a strong individual economic motive. Therefore, the production system should be examined as a whole either by examining interactions (coincidence-based models) or alternative scenarios (the Markov model) rather than exploring variability of individual factors;
- sociotechnical: due to the tight interconnection and group performance, errors should be investigated at the group level rather than in the individual performance;
- psychometric: decision-making is still individual but the perception of risk has a strong social component, due to the weak individual economic motive and tight interactions. The social influences (trust, interests, etc.) along with personal feelings that can also reflect group preferences offered by the psychometric approach can give a better description of the situation that the individual meets.

In all these cases the method for risk assessment can either be the same or different, since this is a matter of the analyst and of the organisation. However, the underlying insights for its application reflecting the respective models differ, thus changing the assessment of risks. Of course, the proposed models are not absolutely the only applicable ones for each situation, since there are no strict boundaries in the applicability of models.

5. CONCLUSIONS

The characteristics of a new work environment require incorporating human factors, risk perception and the effect of systems into risk assessment without requiring expertise in all the dimensions of risk modelling. This combination requires concessions in scientific precision. This paper attempts to simplify, group and combine existing models to obtain a practical approach that meets these requirements. Of course, this approach does not have a solid theoretical basis, but it can help safety engineers of SEs to better identify and assess risks in the context of the modern work environment.

REFERENCES

1. European Commission. SMEs in Europe 2003 (Observatory of European SMEs 2003, No. 7). Luxembourg: Office for Official Publications of the European Communities; 2004. Retrieved August 3, 2009, from: http://ec.europa.eu/enterprise/enterprise_policy/analysis/doc/smes_observatory_2003_report7_en.pdf
2. European Agency for Safety and Health at Work. The changing world of work. Trends and implications for occupational safety and health in the European Union. Forum. 2002;(5):1–12. Retrieved August 3, 2009, from: http://osha.europa.eu/en/publications/forum/5
3. Sørensen OH, Hasle P, Bach E. Working in small enterprises—is there a special risk? Saf Sci. 2007;45:1044–59.
4. Dorman P. The economics of safety, health and well-being at work: an overview. Geneva, Switzerland: InFocus Program on SafeWork, International Labour Organization; 2000. Retrieved August 24, 2009: http://www.ilo.org/public/english/protection/safework/papers/ecoanal/ecoview.pdf
5. European Agency for Safety and Health at Work. Eurostat. Work-related accidents in the EU—the statistical picture (1998–1999). Facts. 2001;(19):1–2. Retrieved August 24, 2009, from: http://osha.europa.eu/publications/factsheets/19
6. Clifton R. The consequences of new enterprise structures. Magazine of the European Agency for Safety and Health at Work. 2000;(2):14–8. Retrieved August 24, 2009, from: http://osha.europa.eu/en/publications/magazine/2
7. European Agency for Safety and Health at Work. New forms of contractual relationships and the implications for occupational safety and health. Summary of an agency report. Facts. 2002;(25):1–2. Retrieved August 24, 2009, from: http://osha.europa.eu/publications/factsheets/25
8. Guadalupe M. The hidden costs of fixed term contracts: the impact on work accidents. Labour Econ. 2003;10:339–57.
9. European Agency for Safety and Health at Work. Prevention of work-related accidents: a different strategy in a changing world of work? European Conference and Closing Event of the European Week for Safety and Health at Work 2001. Forum. 2002;(7)1–8. Retrieved August 24, 2009, from: http://osha.europa.eu/en/publications/forum/7
10. Harrisson D, Legendre C. Technological innovations, organizational change and workplace accident prevention. Saf Sci. 2003;41:319–38.
11. Launis K, Pihlaja J. Changes in production concepts emphasize problems in work-related well-being. Saf Sci. 2007;45:603–19.
12. Leveson N. A new accident model for engineering safer systems. Saf Sci. 2004;42:237–70.
13. Bellamy J, Geyer TAW. Organisational, management and human factors in quantified risk assessment (HSE Contract Research Report. No. 33/1992). London, UK: HSMO; 1992. Retrieved September 3, 2009, from: http://www.hse.gov.uk/research/crr_pdf/1992/crr92033.pdf
14. Campbell DJ. Task complexity: a review and analysis. Acad Manage Rev. 1988;13(1):40–52.
15. Ganster D. Individual differences and task design: a laboratory experiment. Organ Behav Hum Perform. 1980;26:131–48.
16. Lees FP. Loss prevention in the process industries. 2nd ed. Oxford, UK: Reed Educational and Professional Publishing; 1996.
17. Livingston AD, Jackson G, Priestley K. Root causes analysis: literature review (HSE Contract Research Report 325/2001). Sudbury, Suffolk, UK: HSE Books; 2001. Retrieved September 3, 2009, from: http://www.hse.gov.uk/research/crr_pdf/2001/crr01325.pdf
18. Svenson O. The accident evolution and barrier function (AEB) model applied to incident analysis in the process industries. Risk Anal. 1991;11(3):499–507.
19. Humphreys P, Jenkins AM. Dependent failures developments. Reliab Eng Syst Safety. 1991;34:417–27.
20. Kjellén U, Larsson TJ. Investigating accidents and reducing risks—a dynamic approach. J Occup Acc. 1981;3:129–140.

21. Sun H, Andrews JD. Identification of independent modules in fault trees which contain dependent basic events. Reliab Eng Syst Safety. 2004;86:285–96.
22. Smith AJ. The development of a model to incorporate management and organisational influences in quantified risk assessment (HSE Contract Research Report 38/1992). London, UK: HSMO; 1992. Retrieved September 3, 2009, from: http://www.hse.gov.uk/research/crr_pdf/1992/crr92038.pdf
23. Hollnagel E. Coping, coupling and control: the modelling of muddling through [unpublished, invited presentation]. Mental Models and Everyday Activities, 2nd Interdisciplinary Workshop on Mental Models. Robinson College, Cambridge, UK; 1992.
24. Mosneron-Dupin F, Reer B, Heslinga G, Sträter O, Gerdes V, Saliou G, et al. Human-centered modeling in human reliability analysis: some trends based on case studies. Reliab Eng Syst Safety. 1997;58:249–74.
25. Reason J. Human error. Cambridge, UK: Cambridge University Press; 1990.
26. Ryan TG. Task analysis-linked approach for integrating the human factors in reliability assessments of nuclear power plants (TALENT). Reliab Eng Syst Safety. 1988;22:219–34.
27. Fujita Y. Human reliability analysis: a human point of view. Reliab Eng Syst Safety. 1992;38:71–9.
28. Greenstreet Berman Ltd. Preventing the propagation of error and misplaced reliance on faulty systems: a guide to human error dependency (Offshore Technology Report 2001/053). Sudbury, Suffolk, UK: HSE Books; 2001. Retrieved September 3, 2009, from: http://www.hse.gov.uk/research/otopdf/2001/oto01053.pdf
29. Jo Y–D, Park K-S. Dynamic management of human error to reduce total risks. J Loss Prev Process Indust. 2003;16:313–21.
30. Lydell BOY. Human reliability methodology. A discussion of the state of the art. Reliab Eng Syst Safety. 1992;36:15–21.
31. Mosleh A, Chang YH. Model-based human reliability analysis: prospects and requirements. Reliab Eng Syst Safety. 2004;83:241–53
32. Cacciabue PC. Human error risk management for engineering systems: a methodology for design, safety assessment, accident investigation and training. Reliab Eng Syst Safety. 2004;83:229–40.
33. Hollnagel E. Cognitive reliability and error analysis method. Eastbourne, UK: Elsevier Science; 1998.
34. Pyy P. Human reliability analysis methods for probabilistic safety assessment [doctoral dissertation] (VTT Publications 422). Espoo, Finland: Technical Research Center of Finland (VTT); 2000. Retrieved September 3, 2009, from: http://www.vtt.fi/inf/pdf/publications/2000/P422.pdf
35. Wilde GJS. The theory of risk homeostasis: implications for safety and health. Risk Anal. 1982;2:209–25.
36. Tversky A, Kahneman D. The Framing of decisions and the pshycology of choice. Science. 1981;211:453–8.
37. Fessler DMT, Pillsworth EG, Flamson TJ. Angry men and disgusted women: an evolutionary approach to the influence of emotions on risk taking. Organ Behav Hum Decis Process. 2004;95:107–23.
38. Lerner JS, Keltner D. Fear, Anger and Risk. J Pers Soc Psychol. 2001;81:146–59.
39. Mano H. Risk-taking, framing effects and affect. Organ Behav Hum Decis Process. 1994;57:38–58.
40. Weyman AK, Kelly CJ. Risk perception and risk communication: a review of literature (Contract Research Report 248/1999). Sudbury, Suffolk, UK: HSE Books; 1999. Retrieved September 3, 2009, from: http://www.hse.gov.uk/research/crr_pdf/1999/crr99248.pdf
41. DeJoy DM. Theoretical models of health behavior and workplace self-protective behavior. J Safety Res. 1996;27(2):61–72.