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Why person models are important for human factors science

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Human factors science has always been concerned with explaining and preventing human error and accidents. In the past 100 years, the field has shifted focus from a person approach to a system approach. In this opinion article, I provide five reasons why this shift is not opportune, and why person models are important for human factors science. I argue that (1) system models lack causal specificity; (2) as technology becomes more reliable, the proportion of accidents caused by human error increases; (3) technological development leads to new forms of human error; (4) scientific advances point to stable individual characteristics as predictors of human error and safety; and (5) in complex tasks, individual differences increase with task experience. Finally, some research recommendations are provided and ethical challenges of person models are brought forward.

Keywords: accident proneness; system models; person models; technological evolution; individual differences

1. Introduction

Human factors research has always been concerned with improving task performance, reducing human error, and preventing accidents. However, over the course of its history the field has gradually changed focus from describing fallible individuals and erroneous actions towards a system-oriented approach of modelling safety. As stated by Holden (2009, 34): ‘Person-centered safety theories that place the burden of causality on human traits and actions have been largely dismissed in favor of systems-centered theories.’

1.1. Human factors’ shift from a person approach towards a system approach

In the era of Taylorism and Fordism in the first decades of the twentieth century, scientists had a person-oriented focus aimed to increase productivity (e.g., Rosen 1993). Popular methods were proceduralisation, standardisation, training, worker selection, economic incentives, and managerial control. Investigations of industrial accidents showed that accident counts varied considerably between individual workers (Greenwood and Woods 1919). To describe the idea that people differ in their propensity for accidents, Farmer and Chambers (1926; in the UK) and Marbe (1926; in Germany) independently coined the term accident proneness (*unfallneigung*) (Burnham 2009). The heyday of accident proneness and differential psychology was the mid-twentieth century (Burnham 2009; Revelle, Wilt, and Condon 2011): ‘By one count, up to 1960, 3,000 articles had been pub-

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lished on the human factor in just motor vehicle accidents. A very large proportion of such publications contributed to the peak of interest in accident proneness' (Burnham 2009, 145).

World War II saw an introduction of new technologies such as radar and manoeuvrable airplanes (Swain 1990; Meister 1999). Studies showed that even experienced and motivated operators were missing targets on their radar screen, found it difficult to shoot down aircraft using anti-aircraft gunnery, or crashed airplanes in the absence of mechanical failure. The 'Procrustean' approach of adjusting the human to the task requirements became ineffective (Helson 1949; Taylor and Garvey 1959), or as Taylor (1960, 643) put it: 'Machinery had finally outrun the man's ability to adapt.' Survey research by Fitts and Jones (1947) showed that aviation pilots made various types of errors in using their cockpit controls. The authors argued that these errors were not dependent on pilot talent or experience, but could be better explained by the poor design and positioning of the equipment in the cockpit. The field of human factors (also called engineering psychology or human engineering) was initiated, which, by introducing a series of psychological principles, such as shape and colour coding (e.g., Weitz 1944; Hunt 1953), aimed to reduce human error and accidents.

By 1960, cultural emphasis on social equality made the idea of differential accident involvement unfashionable (Burnham 2009). Various statistical concerns were raised against the accident proneness concept, such as the low stability of the number of accidents per person, regression towards the mean, and survivorship bias (e.g., Johnson 1946; Maritz 1950; Arbous and Kerrich 1951; Adelstein 1952; Haight 1964, 1965; Kemp 1970; McKenna 1983; Rodgers and Blanchard 1993). It was increasingly argued that accidents are caused by situational rather than personal factors. Researchers' language changed from statements such as 'the unsafe attitude is the most serious problem in accident prevention' (Scott 1953, see also Culvenor 1997) into statements such as 'accident proneness is a bogey' (Sampson 1971, 913), a 'myth' (Sampson 1971, 913), and a 'hoax' (Page, O'Brien, and Nader 1973, 146), 'a search for a scapegoat' (Haight 2000, 1), and a 'tactical armamentarium used in blaming the victim for industrial accidents' (Sass and Crook 1981, 175). One of the editors-in-chief of the journal *Accident Analysis and Prevention* recently stated that the idea of accident proneness 'died at least fifty years ago' (Elvik 2011, 751), while Ranney (1994) argued that the individual differences approach in identifying safe driving behaviour has various methodological difficulties, and should therefore be abandoned.

From the 1970s, organisational complexity increased, and the scope of human error and safety modelling widened even more. It was argued that upstream factors, such as wrong decisions made in the organisational and managerial spheres, a poor safety culture, and a 'disease of sloppiness' (Sheen 1987, 14), lead to malign workplace conditions such as ambiguity and time pressure. Reason introduced the notion of latent conditions that 'lie dormant within the system for many years before they combine with active failures and local triggers to create an accident opportunity' (2000, 769). He further argued that the person approach has serious shortcomings, as focusing on the individual sources of error isolates unsafe acts from their context. The terms 'fundamental attribution error' (Ross 1977, 186) and 'correspondence bias' (Gilbert and Jones 1986) were introduced, referring to the fact that people overvalue personality-based or actor-based beliefs for observed behaviours, while undervaluing situational explanations. High-profile accidents such as the Three Mile Island incident, the Chernobyl disaster, and the capsizing of the Herald of Free Enterprise made clear that operators at the sharp end should be seen 'as the inheritors rather than as the instigators of an accident sequence' (Reason 1995, 1710).

From the 1990s, a chorus of researchers has proposed a holistic perspective to accidents. To cope with the increasing complexity of work, it became popular to reject empirical work and reductionist thinking, and to see human error as part of normal work. Perrow (1984) introduced the term 'normal accidents,' whereas Reason (1992) argued that 'the way we make errors is very much built into the way we think and the way we think is very adaptive; it is very useful. . . . The same is true of violations. If we had not violated the rules when we were sitting in the caves we would still be there.' Mechanisms such as resilience (i.e., the ability of a system to adjust to disturbances and sustain required operations; Hollnagel, Woods, and Leveson 2006), local rationality (i.e., that human actions leading to accidents made sense under the momentary circumstances; Dekker 2006), and sense making (i.e., the ability to understand uncertainties of an environment by means of interaction; Weick, Sutcliffe, and Obstfeld 2005) entered into the human factors vocabulary. In addition, various holistically oriented theories such as cognitive systems engineering (Hollnagel and Woods 1983), embodied cognition (Clark 1997), distributed cognition (Hutchins 1991), usability engineering (Nielsen 1993), situated design (Lueg and Pfeifer 1997), use-centred design (Flach and Dominguez 1995), activity theory (Nardi 1995), cognitive work analysis (Vicente 1995), and naturalistic decision making (Klein et al. 1993) were proposed as remedies to the presumed deficiencies of the classical information-processing approaches, namely, that these rely on the assumption that a technological system is tractable and well specified (Hollnagel 2012).

1.2. *The pendulum has swung too far*

Without doubt, the emergence of classical human factors engineering around World War II has been a useful progression. The abandonment of the Procrustean approach has liberated workers from fear of blame and punishment and has created the foundations for a culture in which workers can report errors without personal consequences. The empirical human factors that work into the design of displays, control devices, and workplaces have almost certainly contributed to a reduction of the number of errors and accidents.

Figure 1 illustrates why the system approach has merit. The diagram shows that a person is embedded in a system: the person uses equipment within an organisation, which in turn exists within a functioning whole (i.e., everything outside the organisation). Consider a pair of identically trained monozygotic twins who have to work with different equipment. If twin A works with a tool having low stimulus–response compatibility and twin B works with a tool having high stimulus–response compatibility, then twin B is likely to

Figure 1. The broadening of human factors science. Human error and accidents can be explained from a person perspective, focusing on intra- and inter-individual differences in sensory, cognitive, and motor performance. From around 1945, equipment design was taken into consideration in classical human factors engineering. From around 1970s, organizational and managerial factors were also considered in explaining human errors and accidents. In the last couple of decades, researchers have used holistic approaches. The figure is inspired from Reason (2003).

have a lower error rate than twin A. The key point of [Figure 1](#) is that the system influences the probability of human error and that the person should not be modelled without due consideration of systemic influences.

However, concerns have arisen that ‘the pendulum has swung too far’ (Reason [2008](#), 6) towards the systemic direction. The thesis of this article is that contemporary human factors scientists focus all too often on systemic factors, particularly the outer two layers (i.e., organisation, holism) of the onion in [Figure 1](#), while simultaneously ignoring the personal factors that lead to errors and accidents. In the remainder of this article, I discuss five reasons why person models have merit and should be considered in human factors science.

2. Five reasons why person models are important

2.1. *System models have little causal specificity*

James Reason, who has always been a proponent of systemic thinking, has warned of a ‘causal fallout’ (Reason [1999](#), 203) of system models. According to Reason, systemic (remote/latent) conditions promote accidents but have little causal specificity. Reason ([2008](#)) stated that systemic factors are outside the control of managers and are difficult to change or modify by means of safety interventions. Furthermore, the impact of systemic factors is shared by many systems, and their presence does not discriminate between normal states and accidents. Similarly, Sharit ([2006](#), 709) pointed out that although rationalising human error as part of normal work ‘may represent a gracious gesture toward the human’s underlying disposition, it can also dangerously downplay aspects of human fallibility that need to be understood for implementing error reduction and error management strategies.’

It seems tempting to apply an organisational or holistic view in the attempt to cope with complexity. For example, many researchers and practitioners would readily agree that it is important that companies have an adequate safety culture. However, few researchers would agree about what safety culture actually is, and how safety culture should be improved. Although ‘safety culture’ is an intuitively appealing umbrella term, it is a broad construct which is difficult to define or measure (Pidgeon [1998](#); Clarke [2000](#); Guldenmund [2010](#)). This observation is in line with Charles Sanders Peirce (1839–1914) who stated: ‘It is . . . easy to be certain. One has only to be sufficiently vague.’

The weakness of system approaches lies herein that one makes an unfalsifiable claim when stating that persons are under the influence of something bigger, such as an organisation, a complex society, or a functioning whole. Such a statement is ‘not even wrong’ (cf. Peierls [1960](#), 186). Holistic approaches, which promise a progressive insight or a ‘new view on error and performance’ (Dekker [2002](#)), are particularly elusive. Nobody can disagree with a statement such as ‘human error is a symptom of trouble deeper inside the system’ and ‘progress on safety comes from understanding and influencing . . . connections’ (Dekker [2002](#), 372). However, what do these statements mean? What connections and which trouble? These statements have so many meanings that they eventually have none. The more one progresses towards the outer layers of the diagram of [Figure 1](#), the more the causal specificity diminishes. The outermost layer of [Figure 1](#) is drawn without boundaries, taken to mean that each point in the holistic domain has infinitesimal causal specificity.

Person models, such as models of the sensory, cognitive, and motor skills of individuals, are better observable, testable, and falsifiable than system models, and are therefore preferred for cumulative scientific progress. Without denying the influence of systemic factors on human error and accidents, the system approach provides comparatively little concrete real-life meaning.

2.2. As technology becomes more reliable, human error becomes more prominent

Technological development has contributed to improved task performance and safety. In road transport, due to continuous advances in infrastructure and vehicle design, the number of fatal accidents per kilometre driven has shown a steady decline since the 1900s. Aircraft technology has become more reliable, and the rate of accidents per flight kilometre has dropped dramatically since the 1960s (Aviation Safety 2012). It can be deduced that if an accident occurs nowadays, it is unlikely to be the result of a technological malfunction, and likely to be the result of a human error.

In aviation, the idea that improvement of technology brings human error (i.e., pilot crew error and air traffic control error) to the fore was recognised by the International Civil Aviation Organization (1984, 10). They stated that the ‘the number of accidents caused by the “machine” has declined, while those caused by “man” have risen proportionately,’ and illustrated this trend with a figure (cf. Figure 2). They further stated that ‘because of this significant shift in the relationship between man and machine causes, a consensus has now emerged that accident prevention activities should be mainly directed towards the “man”.’ Hollnagel (1993) reviewed selected accident statistics over time, and found that human error became more prominent over the years. Other empirical evidence of this phenomenon is illustrated in Figure 3.

It is acknowledged that the theory proposed in Figure 2 is controversial, because whether the cause of an accident is technological failure or human error is not objectively determinable, but instead a semantic issue that is dependent on the judgement of accident investigators. An analysis of flight accident data by Hobbs (2004) did not confirm the hypothesis that human error is on the rise; instead, his results suggest that pilot error has been the primary flight safety issue since the early days of aviation (i.e., human error has not emerged only after the frequency of technical failures diminished).

To summarise, the effect of optimising the system (i.e., equipment and organisations in Figure 1) may well be that a larger share of accidents is attributable to fallible persons.

Figure 2. Hypothesized percentage of accident causes as a function of time. This figure was created according to a simple model: the expected value of human causes was kept constant over time, while the expected value of technological causes was modeled as a power law. For similar figures, see International Civil Aviation Organization (1984) and Hobbs (2004).

Figure 3. Incident data that is in agreement with the hypothesis that the percentage of human error increases. The figure depicts the annual rate of U.S. Navy/Marine Corps Class A, B, and C mishaps attributable, at least in part, to human error (open circles) and those solely attributed to mechanical/catastrophic failures (closed circles). The figure suggests that the reliability of aircraft has increased and that human error has therefore become relatively more prominent. The numbers near the open circles represent the percentage of incidents that are caused by human error. Data extracted from Shappell and Wiegmann (1996, Fig. 1). Reuse permitted by the Aerospace Medical Association.

In other words, building more reliable systems results in a lower *net* amount of accidents, while increasing the *relative* contribution of persons to these accidents. A simple thought experiment illustrates the idea: if all persons would be working with perfectly reliable equipment in a perfectly reliable organisation, then any error or accident will necessarily be caused by the human worker.

2.3. Technological development leads to new forms of human error

Hollnagel and Woods (2005) argued that if a new technology is invented that exceeds the capabilities of existing technology, this technology is invariably put into use with the aim of improving product quality, safety, and cost effectiveness. New technology results in new sorts of opportunities for malfunction, which in turn are prevented by even newer technology, closing a vicious circle which Hollnagel and Woods (2005) referred to as the self-reinforcing complexity cycle. Accordingly, new technology is usually beneficial in terms of overall safety and/or productivity, but new types of human error and accidents emerge as a side effect.

A classic example of an innovation that has created new forms of human error is fire. The invention of skills and tools to make a fire has not only provided various advantages (improved nutritional quality of foods, obtaining warmth, manipulating physical properties of materials, enabling to work at night) but also has caused that fires are now an important cause of accidental injury and death. Another example is that in modern hospitals, procedures and work flows have become intricate and dynamic, resulting in technology-related medical error and other forms of iatrogenesis (Kohn, Corrigan, and Donaldson 2000; Holden 2011). A third example of technological side effects is the

'ironies of automation' as described by Bainbridge (1983). Many human factors articles have warned about such ironies of automation, including misuse and disuse (e.g., Parasuraman and Riley 1997), loss of situation awareness, complacency, skill degradation, and vigilance decrement. Ironies of automation are ubiquitous and are not only found in safety-critical domains such as hospitals, aviation, and industrial plants. An appropriate example was provided by Hancock and Hancock (2010, 5): 'Grocery store clerks in the US often make egregious errors if the register fails or even if the data are simply entered incorrectly.'

Technological evolution will proceed, arguably with accelerating pace in the coming decades (Movarec 1998; Chaisson 2002; Kurzweil 2005; Schmidhuber 2012) and will therefore lead to new forms of human error. Sheridan (1992) has qualitatively illustrated the progress of human-supervised automation (Figure 4). The trend towards the right top suggests that as technology takes over the low-entropy (i.e., simple, predictable, repetitive, modellable) tasks, the human is left over with the high-entropy (i.e., complex, non-predictable, non-repetitive, abstract) tasks (or 'the tasks which the designer cannot think how to automate,' Bainbridge 1983, 775).

Figure 4. State of progress as a function of the degree of automation and task entropy. There is an array of options for supervisory control, advancing gradually toward the upper-right corner with technological progress. The top right represents ideally intelligent automation, a state unachievable in the near future. From Sheridan (1992, Fig 4.1), see also Sheridan (2002). Reproduced with permission from The MIT Press.

Summarising, technological development results in improved productivity and safety and relieves the human from physical and routine cognitive tasks. However, at the same time, technological development seems to bring human fallibility to the fore. This observation is in line with Bainbridge (1983, 775) who explained the ‘irony that the more advanced a control system is, so the more crucial may be the contribution of the human operator.’

Proponents of the system approach might argue that the new forms of human error provide justification for developing new system models, or for examining new paths within existing system models. Indeed, broader system models are typically justified as a means to cope with the increasing complexity of work (cf. Hollnagel 2012). The drawback is that the new system models will lead to further fuzzification of the description of human error and accidents (see Section ‘System models have little causal specificity’ above).

2.4. Scientific advances point to stable personal factors as predictors of human error and safety

At the beginning of the twentieth century, methods of data collection and statistical inference were relatively immature (Friedman 2001; Rao 2006). Today, sophisticated statistical methods, such as meta-analysis and multivariate analyses, are available, and data-sets are more accessible and larger in terms of number of subjects and temporal coverage. More and more large-scale data analyses are being conducted showing that individual differences are predictive of health and disease. With modern scientific developments, such as the work done in the area of human genetic variation, brain imaging, and data recording/analysis, person models will become increasingly relevant in human factors science.

Researchers have shown that individual differences are often stable and predictive for task performance, human error, and safety. A meta-analysis by Visser et al. (2007) concluded that – although there are various statistical and operational difficulties – accident proneness does exist, as there are more individuals with repetitive injuries than would be expected by chance alone. A recent analysis by Af Wåhlberg and Dorn of traffic accident data of five British bus driver samples showed that accident involvement is ‘surprisingly stable over time’ (2009, 79) and that ‘accident proneness should be revived in traffic research. ... It is not the theory that is deficient, but the previous interpretations of the results’ (2009, 88). Af Wåhlberg (2009, 2012) explained that stability of accidents can only be statistically demonstrated in a longitudinal analysis in which sufficient accident data are gathered, such that the variance of accident counts across individuals is high. Further illustration of this idea is provided in Af Wåhlberg (2009) and Figure 5. Figure 5 shows that a near-perfect ordinal relationship exists between the number of accidents, on the one hand, and the stability of accidents, on the other (Spearman rank correlation coefficient = 0.94). The stability of accidents asymptotes at a Pearson correlation (r) of approximately 0.7, about the same level as the stability of intelligence (described below) and personality in adult age (McCrae and Costa 1994). In other words, the results in Figure 5 suggest that accident proneness is as much a robust trait as intelligence and personality. Personality and intelligence quotient (IQ) can be easily measured with paper and pencil tests. Accident proneness is more difficult to be measured reliably, because accidents are very rare events.

Various other statistical studies have demonstrated that individual characteristics, such as personality or cognitive ability, are predictive of safety and health. Feng and Donmez (2013), for example, reviewed various perceptual, cognitive, and personality (e.g., sensation seeking, impulsivity) factors that are correlated with unsafe driving

Figure 5. Stability of drivers' accidents counts across different time periods versus the mean number of accidents, for 80 samples of drivers (total $N = 5,270,564$; based on 21 different publications). All results are based on registered, rather than self-reported, accident data. It can be seen that the stability coefficient is high, as long as a large number of accidents are observed. Raw data provided by Dr. Anders af Wählberg. For further details see Af Wählberg (2009) and Af Wählberg and Dorn (2009).

behaviours. The authors explained that these individual differences are relevant for developing effective driver-feedback systems.

Cesarini et al. (2009) showed that there is substantial genetic variation in preferences for risk taking, whereas Derringer et al. (2010) predicted sensation seeking from dopamine genes. A review by Turkheimer, Pettersson, and Horn (forthcoming) concludes that all personality traits are heritable at about $h^2 = 0.4$. The authors further warned that attempts to identify specific genes causing individual differences in personality have not yet been successful.

One noteworthy individual differences variable that is predictive of task performance, accident involvement, morbidity, and mortality, is intelligence (Hunter and Hunter 1984; O'Toole and Stankov 1992; Ree and Earles 1992; Hart et al. 2003; Hülshager, Maier, and Stumpp 2007; Batty et al. 2009; Deary, Weiss, and Batty 2010; Whitley et al. 2010). For unskilled jobs, intelligence is not a strong predictor of performance, but the more cognitively complex the job, the higher the predictive value of intelligence (Figure 6). Cognitive complexity may be defined as the number of task elements, the number and nature of their interconnections, the number of decisions that have to be taken, the compatibility between stimulus and response, the uncertainty in predicting the outcome of the task, and the amount of prior learned information that needs to be retrieved from short- and long-term memory (Jensen 2006). More research, longitudinal studies in particular, is required to elucidate the causal pathways and the role of socio-economic status.

Intelligence is highly heritable, with higher correlations of adult IQ among monozygotic twins reared together (0.83) or apart (0.75) than among dizygotic twins reared together (0.39; McGue and Bouchard 1998), and stable (with reported correlations of

Figure 6. Predictive validity (i.e., correlation coefficients) of general mental ability (IQ) for overall job performance scores (supervisory ratings) as a function of job complexity, from low to high. Complexity of each job was estimated by Hunter (1980) based on information-processing requirements measured using U.S. Department of Labor job analysis data. Category 1 (unskilled jobs) included feeding/offbearing jobs. Category 3 included skilled blue collar jobs (e.g., technicians) and mid-level white collar jobs (e.g., upper level clerical, para-professional, mid-level administrative jobs). Examples of Category 4 jobs were computer-systems trouble-shooting and complex manufacturing set-up jobs. Category 5 included professional, scientific, and upper management jobs. Results are from a large meta-analysis by Hunter (1980), and Hunter and Hunter (1984) of 425 studies of job performance ($N = 32,124$), as reported in Schmidt and Hunter (2004, Table 2). Correlations were corrected for measurement error in the supervisor ratings, and for range restriction but not for measurement error in the IQ measure.

0.6–0.9 across multi-year periods; Owens 1966; Hertzog and Schaie 1986; Schwartzman et al. 1987; Mortensen and Kleven 1993; Deary, Pattie, and Starr, forthcoming). Numerous studies have shown how aging affects cognitive functioning and brain morphology (e.g., Salthouse 2010; Royle et al. 2013).

In summary, various stable individual characteristics are predictive of task performance and safety. The predictive validity of individual characteristics points to the importance of person models in human factors science.

2.5. In complex tasks, individual differences increase with task experience

As detailed above, automation has replaced human activity at various repetitive tasks, and the human now has to perform tasks for which no routine may be available. What are the consequences of the changing nature of human work for individual differences?

As early as 1928, Peterson and Barlow suggested that in ‘simpler’ tasks individuals tend to converge or become more alike with practice, and that in more ‘complex’ tasks individuals tend to diverge (see Anastasi 1934; Burns 1937, for reviews). Indeed, in repetitive manual control tasks, experience at a task tends to nullify individual differences. That is, tasks involving bounded domain knowledge and learnable skills involving speed and accuracy of motor movements typically show converging performance over time (Ackerman 2007). For tasks that require inconsistent information-processing components, or tasks which can be performed with different strategies, individual differences may stay constant or even increase with practice (Ackerman 2007). For open-ended knowledge tasks, individual differences will not cancel out with experience either. Ackerman (2007,

Figure 7. Vocabulary test performance (developmental standard scores on the Reading Vocabulary subtest of the Iowa Tests of Basic Skills) from kindergarten (K) through 12th grade, for students scoring at the 1st, 20th, 50th, 80th, and 99th percentiles within each grade. Redrawn from Lohman (1999; Figure 3.1 see also Ackerman (2007). The figure illustrates that task experience leads to increasing individual differences. Reproduced with permission from the American Psychological Association.

237) noted that ‘even though each new task may be closed, the knowledge demands are generally cumulative, and the probability that the individual may not be able to grasp the new task increases with task complexity. When this happens, there will be an increasing difference between the levels of the highest and lowest-performing learners.’ Figure 7 illustrates the idea that for open-ended tasks, in this case vocabulary test performance, individual differences increase with experience.

Research into the effect of practice on individual differences flourished in the first half of the twentieth century: ‘interest in the topic generally waned after the 1930s’ (Ackerman 1988, 288). Kincaid (1925, 34) argued that the question whether practice increases or decreases individual differences is important for determining the ‘relative importance of “heredity” and “environment” in producing individual differences.’ Thorndike (1908, 383) explained this as follows: ‘In so far as the differences amongst individuals in the ability at the start of the experiment are due to differences of training, they should be reduced by further training given in equal measure to all the individuals. If, on the contrary, in spite of equal training the differences amongst individuals remain as large as ever, they are to be attributed to differences in original capacity.’

It is noted that the question whether practice increases or decreases individual differences is somewhat ill defined. The answer to this question depends not only on task consistency/complexity but on various other factors as well: (1) motivation of subjects, (2) how to define equal amounts of practice (same number of trials, or same total time on task), (3) whether to use time measures (e.g., reaction time or task completion time) or amount scores (i.e., the reciprocal of time scores), (4) whether one considers absolute versus relative measures of variability, (5) whether one considers an experimental task or actual job performance, and (6) errors of measurement (e.g., Anastasi 1934; Burns 1937). Furthermore, task complexity is a rather ambiguously defined construct. According to

Moravec's paradox, tasks that are simple for a computer (such as playing chess at a competitive level) are typically regarded as intellectually challenging and complex for a human. In contrast, a task that is simple for an infant, such as recognising faces or sensor-motor tasks, can be formidably complex for a computer (Pinker 2010).

In summary, it seems plausible that despite the many years of mechanisation and automation, individual differences in task performance are still ubiquitous, and may have in fact become larger with time. This is in line with Bereiter (1969) who argued that technology primarily acts as an 'amplifier' rather than an 'equaliser' of individual differences in problem-solving ability.

3. Conclusions and recommendations

The general trend seems to be that human factors scientists resort to system models in an attempt to explain or improve task performance and safety. For example, a recent article '*A strategy for human factors/ergonomics: developing the discipline and profession*' by Dul et al. (2012) presented the findings of a committee established by the International Ergonomics Association (IEA). The article by Dul et al. – which, based on current citation counts, promises to become a citation classic – argued that human factors science 'takes a systems approach' (377), with a system being rather loosely defined as 'a set of interacting and interdependent components that form an integrated whole' (379). The article has a globalistic character and discusses topics such as the worldwide change of work, population aging, sustainability, and so forth. Although the objectives of Dul et al.'s article are laudable, it is rather disappointing that it gives little attention to reductionist person-oriented thinking. For example, the article makes no mention of scientific advances in neuro-ergonomics, molecular genetics, brain imaging, brain-computer interfaces, differential psychology, or other types of research achievements showing how human error can be predicted and prevented at the individual level.

This article provided some counterforce to the recent popularity of systemic thinking. Of course, system models are not rejected as safety tools. System models coexist with person-centred models and the two approaches are complementary to each other. As pointed out above in relation to Figure 1, persons always operate in an environment (system), and it would be unwise to ignore the conditions under which humans work. Indeed, it is fundamentally silly to adopt an extreme position in the person versus system debate (silly is a term that philosophers sometimes use, see Ackerman, *forthcoming*). Persons and the systems in which they operate both have explanatory value for human error and accidents. For instance, it is possible to create an extremely safe system, such that no person, no matter his mental/physical state, would ever induce an accident. Using a straight-jacket and suicide watch might be the ultimate examples of preventing a person from harming himself and others. Conversely, even the most highly skilled person will produce accidents if this person is forced to work with technology that does not fulfil basic human factors requirements regarding vigilance, reaction time, and/or display design. A helicopter with excessive phase lags or time delays, for example, will result in dangerous helicopter-pilot couplings, even for the most skilled and talented pilots. The aim of the present work was not to discredit system approaches altogether. Instead, the aim of the present opinion article was to highlight perils of the system approach, and to bring the person approach to the attention of researchers and practitioners.

I argued that technological development leads to increased task complexity and new forms of human error. Although the total number of accidents decreases on a year-to-year basis, an increasing proportion of the remaining accidents are attributable to human error.

Training and experience at a complex task may increase, rather than decrease, the magnitude of individual differences. Scientific process, such as the analyses of large databases in molecular genetics, and improvements in temporal and spatial resolution of brain imaging techniques, make personal factors more and more identifiable in human factors science, as well as in personalised medicine. Others have also noted that persons (rather than systems) become the focal point of attention when technology progresses. Hancock, Hancock, and Warm (2009, 481) argued that 'it is probable that a continuing increase in computational power and associated memory storage capacities will lead to circumstances in which each and every single person can be coded as, and treated as, a separate individual and therefore not necessarily as a representative part of any group, sample or population.' Parasuraman and Riley (1997, 250) stated that 'individual differences in automation use are ubiquitous.'

Although system models appear to be progressive and comprehensive, they do not provide the specific predictions that reductionist empirical models do. Reductionist thinking and empirical testing in the lab remains one of the most important human factors methods. There is a wealth of interesting classic human engineering papers, such as the 'knobs and dials' research done in the 1940s, 1950s and 1960s, on how to pragmatically improve the safety and efficiency of human-machine interaction. Unfortunately, most of this work seems to be forgotten (see Sheridan 2002 for some discussion about the history of human factors science). Proctor and Vu also questioned recent systemic approaches, arguing that much of the progress in human factors research is due to the information-processing approach at the person level: 'Because human performance in all applied contexts boils down to actions of individual people, understanding how humans process information will necessarily continue to provide the foundation for human factors in the future' (2010, 645).

What recommendations can be derived from the present study? One suggestion is that researchers should not downplay human fallibility. Some individual characteristics are stable and predictive of human error and accidents. Individual traits may help explain why some safety interventions are effective and others are not. A good illustration of the importance of person-oriented thinking can be found in road transport, although similar recommendations may apply to other fields, such as aviation, rail, nuclear, and medical domains.

In road transport, there is no doubt that (systems) engineering developments, such as improvements in road infrastructure and crashworthiness of cars, have contributed to a reduction of accidents. However, certain person-oriented road safety problems have proven to be very difficult to solve (Elvik 2011). Among those unsolved issues is the fact that young male drivers are involved in substantially more severe road traffic crashes than young female drivers, a problem that occurs in every nation, and 'is so robust and repeatable that it is almost like a law of nature' (Evans 1991, 41). Based on some robust statistical patterns, Evans (2006) suggested that sex differences in accident rates are innate and originate from sex differences in testosterone levels. Dahl (2008) considered several other biological, developmental, and neurobehavioural factors that are relevant to young drivers' accident risks. Interestingly, road safety researchers rarely document that there may be a biological basis for risk taking, and an explanation of observed gender differences is often sought in environmental factors (e.g., lifestyle, mileage, types of roads, and vehicles driven). Af Wahlberg (2009) recently showed that drivers' accident counts are quite stable over time, pointing to some common risk factor, or accident proneness, among drivers. Applying a person-oriented perspective may help explain why formal driver training programmes are ineffective for improving safe driving among young

drivers (cf. Groeger and Banks 2007). Recognising the importance of individual differences may also be useful in design, for example, in developing personalised driver assistance systems that target unsafe driving (cf. Feng and Donmez 2013).

Of course, a person approach raises some ethical and legal questions, and is certainly less politically correct than a system approach. Some ethically challenging questions are the following. (1) If it can be determined that it is statistically likely that a person will be involved in a future accident, then (how) should a licensing authority react to that? Should personal training or coaching be offered? (2) How to set thresholds for granting or renewing a license/contract? For example, should we be issuing driver's licenses to 'accident prone' persons? An overly tolerant criterion will lead to harm, while setting the criterion too strictly may constrain individual freedom. (3) If research indicates that certain biological or genetic factors are powerful predictors of safety, then what are the practical and legal implications of these findings? A review by Turkheimer, Pettersson, and Horn (forthcoming) into genetics and personality argued that 'if it ever became possible to predict personality from genomic data alone, there would be profound ethical issues involved.' (4) How to assure confidentiality? Evidence from the 1950s, an era when accident proneness research was thriving, shows that employees who were identified as accident-prone faced discrimination from their colleagues (Burnham 2009). (5) Suppose that accident proneness data starts being used by companies or governments, then who should be in control of this process, and who should be the owner of the data? Privacy laws in Europe are known to be very strict, but some voices argue that the 'end of personal privacy' is near in our digitised society (Madan et al. 2009). Similar questions are now being asked in other domains such as personal genomics and genetic fingerprinting. Arguably, privacy and other ethics concerns will become increasingly important in human factors science.

A final recommendation, as suggested by one of the reviewers, is to compare a person model and a system model in a randomised controlled trial. Although the amount of variance explained cannot be compared, as the system approach cannot compute such a thing, the overall reduction in accident numbers can be compared between, for example, selection of workers according to a certain test and/or training, and a systemic safety intervention (e.g., to improve safety culture by means of a specific intervention) within companies. Putting numbers on the different approaches would bring the respective usefulness of person models versus system models in an evidence-based perspective.

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