The ETTO principle as ETTOing – or Occam's Razor redux

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Abstract

The Efficiency-Thoroughness Trade-Off (ETTO) principle is a convenient way to characterise the adjustments that are an essential part of everyday performance in complex socio-technical systems. This trade-off between efficiency and thoroughness, however, applies not only to how people cope with the complexity at work (and at leisure), but also to what scientists do when they try to understand other people's behaviour. As such, the ETTO Principle can be seen as an instance of Occam's Razor. The talk will discuss how the ETTO principle can be applied to analysis and meta-analysis alike.

> *"Principles taken upon trust, consequences lamely deduced from them, want of coherence in the parts, and of evidence in the whole, these are every where to be met with in the systems of the most eminent philosophers, and seem to have drawn disgrace upon philosophy itself."*
> *David Hume (1711–1776). A Treatise of Human Nature (Introduction)*

What is the ETTO principle?

It is a fundamental characteristic of human performance, whether individual or collective, that the resources needed to do something often – if not always – are insufficient. In today's hectic workplace the most frequent shortcoming is probably a lack of time, but other resources – such as information, manpower, materials, and energy – may equally well be in short supply. People nevertheless in most cases manage to do *what* they should by adjusting *how* they do it to meet the current conditions. In practical terms they manage to establish – and maintain – a continuous balance between demands and resources. The ability to adjust performance to match the conditions can be described as if it involved a trade-off between efficiency and thoroughness – or briefly as if it used an Efficiency-Thoroughness Trade-Off (ETTO) principle (Hollnagel, 2009).

The ETTO principle refers to the fact that people (and organisations) as part of what they do frequently – it not always – must make a trade-off between the resources (primarily time and effort) they spend on preparing and monitoring an activity and the resources (again primarily time and effort) they spend on doing it. If safety and quality are the dominant concerns, the trade-off may favour thoroughness over efficiency. Conversely, if throughput and output are the dominant concerns, the

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trade-off may favour efficiency over thoroughness. It is a basic assumption of the ETTO principle that it is impossible to maximize efficiency and thoroughness at the same time. On the other hand, an activity cannot expect to succeed, if there is not a minimum of either.

The term ***efficiency***, as it is used by the ETTO principle, means that the resources used or needed to achieve a stated goal or objective are kept as low as possible. The resources may be expressed in terms of time (to completion), materials, money, psychological effort (workload), physical effort (fatigue), manpower (number of people), etc. The appropriate level or amount is determined either by a subjective evaluation of what is sufficient to achieve the goal, i.e., good enough to be acceptable by whatever criterion is used, or by external (company or authority) requirements and demands. For individuals, the decision about how much effort to spend is usually not explicit but rather a result of perceived demands, habits, social norms, and established practice. For organisations, the decision is more likely to be the result of an open consideration – although making this choice is subject to the ETTO principle as well.

The term ***thoroughness***, as it is used by the ETTO principle, means that an activity only is carried out if the individual – or the organisation – has verified that the necessary and sufficient conditions are in place, so that the activity will achieve its objective without creating unwanted side-effects. More formally, thoroughness means that the pre-conditions for an activity are in place, that the execution conditions (resources, tools, and competence) can be ensured, and that performance is monitored and controlled so that the outcome(s) will be the intended one(s).

Individual, collective, and organisational ETTO rules

The ubiquity of making such efficiency-thoroughness trade-offs, colloquially known as ETTOing, can be illustrated by listing a number of ETTO rules. The rules represent the reasoning or justifications we use when we make a trade-off – although this rarely is made clear unless we are required to provide an explanation for one reason or the other. The rules listed below apply to the way people work individually. They can easily be found in the general human factors literature, in studies of work, etc., although the list makes no claim to being exhaustive.

- 'It looks fine' – so there is no need to do anything, meaning that an action or an effort can safely be skipped.
- 'It is normally OK, there is no need to check' – it may look suspicious, but do not worry, it always works out in the end. A variation of that is 'I/we have done this millions of times before' – so trust me/us to do the right thing.
- 'It is good enough for now (or for this kind of work)' – meaning that it passes someone's minimal requirements.
- 'It will be checked, or done, by someone else later' – so we can skip this test or action now and save some time.
- 'It has been checked, or done, by someone else before' – so we can skip this test or action now and save some time. A combination of this rule and the

preceding is clearly unhealthy, since it opens a path to failure. It happens every now and then, usually because different people are involved at different times.
- '(Doing it) this way is much quicker' – or more resource efficient – even though it does not follow the procedures in every detail.

Since work always takes place in a social context, some of the ETTO rules apply to work as a social or collective rather than as an individual activity. The following are some examples:

- 'We always do it in this way here' – so follow the norm and do not worry if the procedures say something else.
- 'We must get this done' (before someone else beats us to it or before time or resources run out) – therefore we cannot afford to follow the procedures (or rules and regulations) in every detail.
- 'It must be ready in time' – so let's get on with it. (The need to meet a deadline may be imposed by the company, the bosses, or by the group itself).
- 'If you don't say anything, I won't either' – in this situation one person has typically 'bent the rules' in order to make life easier for another person or to offer some kind of service.

Just as there are social ETTO rules, there are also organisational ETTO rules. Some of the more common ones are:

- 'The negative reporting rule', which means that only deviations or things that go wrong should be reported. In consequence of that, the absence of a report is interpreted as meaning that everything is well. The rule clearly improves efficiency, but may have consequences for safety.
- 'The visibility-effectiveness problem.' Many organisations realize that it is important for managers to be visible in the organisation, which means that they should spend time to find out what is going on and become known among the people they manage. On the other hand, managers are often under considerable pressure to be effective and to perform their administrative duties promptly, even when deadlines are short. They are therefore required to be both efficient in how they accomplish their administrative duties, and thorough in the sense that they behave like good managers.
- 'Report and be good.' In the relation between an organisation and a subcontractor or a supplier, the safety ethos prioritizes openness and reporting of even minor mishaps. Subcontractors and suppliers are thus often under pressure to meet the organisation's standards for openness and reporting. But at the same time they may suspect that they will suffer if they have too many things to report, while a competitor that reports less may be rewarded. In ETTO terms it is thorough to report everything and efficient to report enough to sound credible but not so much that one loses the contract.

People who ETTO

Examples of people making an ETTO are easy to find. The following is one of several cases described in one of the classic works in industrial safety (Heinrich, 1931).

> "A mill employee slipped and fell on a wet floor and fractured his kneecap. For more than six years it had been the practice to wet down too great an area of floor space at one time and to delay unnecessarily the process of wiping up. Slipping on the part of one or more employees was a daily occurrence. The ratio of no-injury slips to the injury was 1,800 to 1." (Op cit, p. 94)

The ETTOing in this example is partly by the company – or by the people who clean the floor – where getting the cleaning done quickly (too great an area and no wiping up) was more important than doing it thoroughly, and partly by the employee who perhaps walked a little too quickly or carelessly. In cases like this, it is a safe bet that no one did this for the first time when things went wrong. It was rather a case of a practice that had been established over six years, and which everyone had become accustomed to.

Here is another example (NTSB, 2001).

> On March 28, 2000, about 6:40 a.m. a freight train traveling 51 mph struck the passenger side of a school bus at a railroad/highway grade crossing near Conasauga, Tennessee. The accident occurred as the school bus was crossing the tracks at a speed of approximately 15 mph. During the accident sequence, the driver and three children were ejected. Two ejected passengers received serious injuries and one was fatally injured. The driver, who had been wearing a lap/shoulder belt that broke during the crash sequence, received minor injuries. Of the four passengers who remained inside the bus, two were fatally injured, one sustained serious injuries, and one, who was restrained by a lap belt, received minor injuries.

According to the required procedure at the grade crossing, the driver should have stopped at least 15 feet from the nearest rail, turned off her radio, and opened the door and window, in order to listen and look for an approaching train. But the driver did not do that. Considering that it was early in the morning, that she was doing a routine job, and that she had a timetable to meet, it is hardly surprising that she made a trade-off between efficiency (getting the children to school on time) and thoroughness (stopping, turning of the radio, etc.). The NTSB report indeed noted that she had crossed the tracks without stopping at least eight other times before the accident. They also noted trade-offs by the school district, the Federal Railroad Administration, and the Federal Motor Vehicle Standards. In other words, ETTOing all around.

ETTO versus 'human error'

Accident investigation and risk assessment have since the 1950s increasingly focused on the human factor, and with even greater intensity since March 28, 1979. Countless books and papers have been written, and countless presentations given about how to identify, classify, eliminate, prevent and compensate for 'human error.' The bias of practically all approaches to risk and safety is that failures and successes have different origins. There is therefore little to be gained from studying the latter. Instead, all efforts should be focused on understanding why things go wrong and why humans make 'errors.'

To invoke the notion of 'human error' is unquestionably the most common ETTO in safety management. It is efficient because it provides a single and simple explanation; but it lacks thoroughness because the explanation is insufficient, if not outright wrong. That it is insufficient can be seen from the many proposals for detailed classifications or taxonomies of 'human error' – from the simple distinction between 'errors of omission' and 'errors of commission' to detailed lists of 'internal error modes' and 'psychological error mechanisms.' That it is wrong should hopefully be clear even from the few examples given here (if not, see Hollnagel & Amalberti, 2001). Humans try to balance efficiency and thoroughness in everything they do; indeed, they are usually expected to do so. It is only in hindsight, when the outcome is wrong, that the choice of efficiency over thoroughness conveniently is labelled 'human error.'

The ETTO principle describes the common trait of people at work, that they adjust what they do to match the conditions – to what has happened, to what happens, and to what may happen. It proposes that this efficiency-thoroughness trade-off is both useful and ubiquitous. While the adjustments in some cases may lead to adverse outcomes, these are not due to errors and malfunctions, but to the very same processes that lead to successes. The ETTO Principle thus removes the need for specialised theories and models of failure and 'human error', and offers a viable basis for effective and just approaches to both reactive and proactive safety management.

There are several practical benefits from studying ETTOing in practice. Most importantly, by paying attention to what people actually do ('work-as-done'), instead of to what they should do ('work-as-imagined'), it becomes possible to detect the problems that people face in their everyday work and to recognise the clever solutions they find. Because these solutions overcome the problems, neither problems nor solutions can be found in the traditional event reports or work analyses. But recognising the trade-offs that people make can be used to identify potential flaws in the system, as well as to develop more efficient ways of working. Another benefit is that it becomes unnecessary to look for someone to blame when things go wrong. This will not only be a benefit to learning from experience, but also create a better safety climate in the company. Finally, it helps us to avoid the ETTO fallacy, i.e., to require that people are both efficient and thorough at the same time – or rather that they are thorough when with hindsight it was wrong to be efficient!

ETTO as generalised human factors theory

The recognition that the human is not a *calculus ratiocinator*, or an information processing system, and that human performance therefore is characterised by various forms of trade-offs is by no means not new. There are, indeed, several psychological or human factors theories that describe just that.

An obvious place to start is the well-known speed-accuracy trade-off, also known as Fitts' Law (Fitts, 1954). This law predicts that the time required for a rapid, aimed movement of, say, a lever or a computer mouse, from a starting position to a final target area, is a function of the distance to the target and the size of the target. Fitts'

law has been applied to user interface design, to predict the performance of operators using complex systems, and to predict movement time for assembly line work.

Moving from physical movements to decision making, and to cognitive functioning in general, an early recognition of the trade-offs that people made is the notion of "muddling through" (Lindblom, 1959). The idea in "muddling through" is that people make decisions by going through the following stages: (1) define the principal objective; (2) outline a few, obvious alternatives; (3) select an alternative that is a reasonable compromise between means and values; and finally (4) repeat the procedure if the result is unsatisfactory or if the situation changes too much. Decisions are, in other words, not made by following the principles of the *homo economicus* – the rational decision maker. A slightly different formulation is given by Herbert Simon's description of bounded rationality or *satisficing*. This refers to the tendency to select the first option that meets a given need or select the option that seems to address most needs rather than the "optimal" solution (March & Simon, 1958; Simon, 1947).

There is, however, an interesting difference in the explanation of satisficing and "muddling through". In the case of the former, Simon argued that human beings lack the cognitive resources to optimize; satisficing is therefore due to the limitations of the human information processing system – a theoretical stance that has largely been discredited. In the case of "muddling through", Lindblom argued that the reason was to be found in the external conditions of decision making. Although he accepted that the intellectual capacities of people might be insufficient, he also noted that rational decision making was:

> "... absurd as an approach to policy when the time and money that can be allocated to a policy problem is limited, as is always the case. Of particular importance to public administrators is the fact that public agencies are in effect usually instructed not to practice (*rationality*). That is to say, their prescribed functions and constraints – the politically or legally possible – restrict their attention to relatively few values and relatively few alternative policies among the countless alternatives that might be imagined." (Simon, 1947, p. 80)

In other words, the conditions of work forces decision-makers to make a trade-off thoroughness for efficiency. Another, and more recent, example of that is provided by the theory of naturalistic decision making (Klein, 1993).

ETTOing in science

If people in general make trade-offs between efficiency and thoroughness, it stands to reason that scientists and researchers also do, both in going about their daily lives, and in thinking about how others go about their daily lives. In other words, the scientific theories and models that we use generally represent an efficiency-thoroughness trade-off, where efficiency is more important than thoroughness – although the opposite ought to be the case. (It may be a small comfort, that the same tendency can be found in all sciences, with economics probably being the most conspicuous example.)

When looking for explanations expressed as scientific theories or hypotheses, people have a strong preference for simple and single explanations, meaning theories that rely on a single principle but that nevertheless are used to explain – or give sense to – rather complicated phenomena. Since there are so many examples of that in the behavioural (and social) sciences, the selection that follows is limited to what broadly may be called human factors.

The inverted U-curve between arousal and performance

The Yerkes–Dodson law is an empirical relationship between arousal and performance, more precisely that performance increases with physiological or mental arousal. However, when levels of arousal become too high, performance decreases. The process is often illustrated graphically as a curvilinear, inverted U-shaped curve which increases and then decreases with that purports to explain why people take certain actions to either decrease or increase levels of arousal.

The idea that the relationship between arousal and performance can be described in terms of an inverted U-shape curve is attractive. It is simple to understand and can apparently explain a number of different phenomena. It is, however, also seriously oversimplified, hence not very thorough. One problem is that neither arousal nor performance are easy to define. In fact, the original experiments were neither about performance nor about arousal (Yerkes & Dodson, 1908). Yerkes and Dodson examined "the relation between stimulus strength and habit formation" in laboratory mice, by giving the mice electrical shocks to see how quickly they learned to take one path rather than another in a maze. The conclusion was that habits are formed most rapidly at medium level shocks. Expressing that as an inverted U-curve for arousal and performance requires a leap of imagination. (To their credit, Yerkes & Dodson did not make or even suggest this leap. In fact, their paper ends as follows: "Naturally we do not propose to rest the conclusions which have just been formulated upon our study of the mouse alone. We shall now repeat our experiments, in the light of the experience which has been gained, with other animals".)

Workload

Another simple but powerful idea is that excessive workload affects performance negatively. (The similarity to arousal and performance is probably not a coincidence.) Ever since Miller published his 'magical number seven' paper (Miller, 1956), it has been taken for granted that humans have limited capability for processing information – Neisser (1982) notwithstanding. Excess workload can of course lead to reduced human performance in terms of slower task performance and lower accuracy (often expressed as an increasing number 'errors'). But the term is used far more widely, to provide convenient explanations of a multitude of phenomena.

The problem with workload – and several other concepts in human factors as well as other sciences – is that it is intuitively meaningful to most people. We therefore rarely bother to ask for a precise definition. Yet despite decades of research and thousands of papers and book, there is no agreed definition of workload. Neither is

there one agreed method of assessing or modelling it, although not for the lack of trying. In that sense workload suffers the same fate as its cousin *fatigue*. In 1921 Bernard Muscio produced a penetrating analysis of fatigue and recommended, among other things, that "the term fatigue be absolutely banished from precise scientific discussion, and consequently that attempts to obtain a fatigue test be abandoned" (Muscio, 1921, p. 46). His reasoning can equally well be applied to workload, but the impact would probably be the same. The convenience of using simple terms (efficiency) by far overrules the lack of meaning (thoroughness).

Situation awareness

One cannot mention the inverted U-curve and workload without also mentioning situation awareness. Much has been said about it, both pro and con. The many debates are by themselves evidence that using a construct – a hypothetical intervening variable – such as situation awareness, is seen as an efficiency-thoroughness trade-off by many. This comment from Charles Billings puts it neatly:

> ''The most serious shortcoming of the situation awareness construct as we have thought about it to date, however, is that it's too neat, too holistic and too seductive. We heard here that deficient SA was a causal factor in many airline accidents associated with human error. We must avoid this trap: deficient situation awareness doesn't 'cause' anything. Faulty spatial perception, diverted attention, inability to acquire data in the time available, deficient decision-making, perhaps, but not a deficient abstraction!'' (Billings 1996).

Yet despite the obvious lack of thoroughness of situation awareness, the efficiency – or perhaps the facileness – of using it as an explanation ensures that it will continue to be used for some time to come.

SRK

While the temptation of single-factor theories seems to be in no danger of waning, some things clearly require a little more detail or thoroughness. A good example of that is the so-called skill-based, rule-based, knowledge-based description of human cognition, commonly referred to as the SRK framework (Rasmussen, 1979). The SRK framework introduces a distinction between three characteristic ways of human information processing, in order to explain characteristic differences in how people accomplish their tasks.

- Skill-based behaviour requires very little or no conscious control to perform or execute an action once an intention is formed; it is thus akin to sensorimotor behaviour. Skill-based performance, such a riding a bicycle, is smooth, automated, and consists of highly integrated patterns of behaviour control. Skill-based behaviour is efficient but not very thorough.
- Rule-based behaviour depends on the use of rules and procedures to select a course of action in a familiar work situation. The work can be reasonably effective, because the pre-compiled thoroughness of the rules allow attention to be focused on the work to be done.

- Knowledge-based behaviour is used for situations that are novel and unexpected. These require considerable attention and reasoning before something can be done. One output of that may be a procedure for the activity, which means that it becomes rule-based. Since most, if not all, of the time is spent trying to comprehend the situation and thinking about what to do, efficiency is low – but thoroughness hopefully correspondingly high. And cognitive workload (sic!) will be greater than for using skill- or rule-based behaviours.

The SRK framework has been widely used and has even been the basis for a specific theory of 'human error' (Reason, 1987) and a design principle (Rasmussen & Vicente, 1989). Yet it is clearly a simplification, and furthermore rests on another simplification – namely the notion that the human (mind) can be described as if it was an information processing system.

The examples, as well as great many other, illustrate the common characteristics of trading off thoroughness for efficiency in scientific analyses. One is that explanations are relying on substitution, meaning that the explanation is expressed in terms of concepts (and theories) that themselves are simplifications and in need of articulation. A second is that the explanations rely on overgeneralisations, meaning that they are applied very broadly and with insufficient discrimination. Finally, the explanations are immune against falsification, both because they are so vague that they can be interpreted almost at will, and because they do not readily allow predictions (e.g., Dekker & Hollnagel, 2004). They are nevertheless effective because they provide the illusion of an explanation, and because they are easy to communicate to others.

Occam's razor redux

Simplifying scientific explanation is, however, generally considered a strength rather than a weakness. This tradition goes back at least to the middle ages and is often ascribed to the Oxford theologian and logician William of Ockham (c. 1285–1349). It is commonly referred to as Ockham's razor or the Law of Parsimony and expressed thus: "other things being equal, a simpler explanation is better than a more complex one." (The common Latin version is: *entia non sunt multiplicanda praeter necessitatem*.) In other words, simpler explanations should be preferred (efficiency) until they lead to loss of explanatory power (thoroughness).

In William of Ockham's own work, the 'razor' was applied to the type of knowledge he called abstraction, but not to the two others (intuition and faith). His concern was an analysis of rational knowledge, and the 'razor' was applied in an attempt to eliminate concepts and ideas that were unnecessary. The aim was, however, not to find the simplest possible explanation if this meant that understanding and precision – explanatory power – suffered. In other words, efficiency should not be allowed to outweigh thoroughness, but an appropriate balance should be struck.

The Law of Parsimony is good advice indeed, but as the examples above have shown, the simplification can be taken so far that thoroughness is irrevocably lost. There may be several explanations for these – each of which, of course, may fall

prey to the very effect they aim to explain. In consequence of that we should acknowledge that it is unlikely that a single explanation that will suffice, but that multiple factors and conditions need to be considered together. Yet it is no oversimplification to note that the conditions of scientific or intellectual work have changed dramatically from the days of William of Ockham to the present. In the days of Scholasticism the emphasis was on clear and convincing arguments, while today the emphasis is on finding solutions and on communicating them to others before somebody else does.

Conclusion: ETTOing is unavoidable

Jonathan Swift once made the observation that 'the only true map of Ireland is Ireland' - meaning that a model is always a simplification. In relation to human factors, it means that the only true representation a phenomenon is the phenomenon itself or – less demandingly – that the description / explanation of something must be proportional in detail to the phenomenon being described.

There is general agreement that the world around us, and more specifically the work environment, is getting increasingly complicated and intractable. The irony is that this apparently leaves less time and allows less effort to develop explanations. Researchers and practitioners are expected to be more efficient, in the sense of being able to explain events and phenomena in a way that is easy to understand, easy to communicate, and easy to turn into tangible – if not always practical – action.

While such trade-offs always have been present – since it is a pervasive trait of human performance – they were less conspicuous until a few decades ago. Today the accelerating demands to performance and the increasing complicatedness of working environments make the trade-offs both more frequent and easier to spot.

The bottom line is that we cannot avoid making these trade-offs – simply because of limitations in time and resources – but that we should realise and accept that it happens, and acknowledge the unavoidable limitations on what we can accomplish. The ETTO principle may help us to do that, but the ETTO principle also applies to itself. It is a simple explanation, which is good enough, rather than a more complicated (but not necessarily complex) explanation, which would be far more thorough.

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