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The laws controlling engineers

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ABSTRACT: In a previous article, the author outlined a number of the laws that engineering students should be informed of. Those were, of course, *laws* in a legal sense, a mixture of items, some being what is termed *common law* and others with a legislative background, all quite important, because these have extensive influence over many human activities. However, those laws are not the only ones under which engineers work; there is a range of other laws that actually come within the technological subjects in an engineering curriculum. These laws are derived from science and are so precisely and pedantically taught that certain implications of them are likely to be missed. Finally, there are a few *other laws*, which influence work situations in ways that may be irritating, embarrassing, saddening or humorous, depending on how they affect the observer, but all relate, in some way, to the truth of society around us. In this article, the author gives the principal *science-based laws* with mention of their implications, and provides examples of *other laws* and how they relate to an engineer's work.

INTRODUCTION

In a previous article, the author briefly skimmed through laws that relate to employment, industrial relations, contracts, insurance, occupational health and safety (OH&S), negligence and intellectual property, and gave reasons why engineers need to know at least the outline behind, and of, these laws [1]. It also showed, *inter alia*, that *law* is not a dull subject, it can be very interesting, even (and particularly) for professional engineers [1].

But those laws do not directly impinge upon an engineer's work situation; they are peripheral to what an engineer does. They may affect how an engineer operates (for example, how a contract for engineering work is framed and applied), but they are not about engineering *per se*. Which leads to a rhetorical question: are there laws that relate closely to an engineer's work? And if so, what are they?

FIRST A DEFINITION

What is meant when one refers to *engineering laws*? How are they defined? Incidentally, are they analogous to any of those of common law origin or from legislation?

The *Oxford Dictionary* provides more than a column of uses of the word *law*, too many to go through [2]. *Webster's New Standard Dictionary* is more succinct, stating: *a rule of action established by authority; rule or axiom of science or art*, plus more items [3]. But those two definitions from Webster are sufficient, because *engineering laws* are a combination of those two; they are established by authorities (hence they are similar to common law or legislation) and are rules or axioms. Another reference gives: *a formal statement of facts observed in natural phenomena* [4]. That is enough to show what is meant by *engineering laws*. Now to some examples.

NEWTON'S LAWS.

The first and probably most obvious example of such laws are those given by Isaac Newton. These laws control motion and the physical interaction between machine components; they are, therefore, extremely important to mechanical engineers.

Why only mechanical engineers? The reason: mechanical engineers design and build and deal with things that move, buzz back and forth, or spin round, and those things are controlled by Newton's Laws. That is unlike civil engineers who, in general, try to avoid having such movements in what they design and build; they hand over to mechanical engineers the moving parts of their buildings, such as elevators and escalators. The third traditional discipline, electrical engineers, deal with something invisible and intangible, which, though moving, does not respond to Newton's Laws. Mechanical engineers (and their descendants, such as aeronautical engineers) depend on Newton's Laws for the design of systems, and their work is controlled by those systems.

There is something enticingly simple about Newton's First Law: *a body remains at rest or maintains a constant velocity in a straight line unless acted upon by an external force* [5] (*Britannica* has been used due to the need to reduce the author's library). The Second Law is usually expressed algebraically by the equation: $f = m \times a$ (*force equals mass times acceleration*); it is also useful to think of this as acceleration equals force divided by mass, so the heavier an item is the more slowly it accelerates. The Third Law is as disarmingly simple as the First Law and relates to equality of forces: *the force of one body* (the first) *exerts on another* (the second) *is equal in magnitude and opposite in direction to the force the second body exerts on the first*. This is commonly phrased as *action and reaction are equal and opposite*, and implies that momentum (a product of mass and velocity) is conserved.

Reading those definitions prompts one to wonder why so many centuries elapsed before someone observed what happens, thought about it, put two and two together, and reached those conclusions. Laws from common law or legislation can be modified or changed, but these three laws cannot be challenged. Mechanical engineers are stuck with them; they govern the way all systems move.

But is that totally true? Well, not quite, later work, in the last century or so, has shown that under conditions more extreme than those that are experienced here on the ground, or nearby, Newton's Laws do not apply. For example, even though no one has ever physically reached any velocity close to that of light, it is generally accepted that Newton's Laws do not apply under that condition. However, as far as the common Earth-bound engineer is concerned, Newton's Laws fix the behaviour of physical systems.

An understanding of gravity comes out of Newton's Laws, and appreciating gravity's impact is extremely important to engineers. It is common knowledge that things released from support fall *down*, but mechanical and civil engineers fight gravity with much of their work, which leads to the author stating the Law of Selective Gravity: *an object will fall so as to do the most damage* [6].

There are, in Newton's Laws, some reflections of ordinary everyday experience. In line with the First Law, one comes to recognise that, unless one does something and takes action, the results desired will not be obtained, and external forces may push in unwanted directions. The Second Law follows from that, the harder one pushes, the faster change will occur. The Third Law can be applied to arguments, the opposition encountered tends to be a strong as the argument presented.

The Law of Systems Inertia follows from the First Law above: *a system that performs a certain function or operation in a certain way will continue to operate in that way regardless of the need or of changed conditions* [6].

THERMODYNAMICS

The history of the Laws of Thermodynamics does not relate to one person, as did the laws of motion, above; several scientists painstakingly put them together over a comparatively long period [5]. And, unlike the laws of motion, they relate to the work performed by all three of the traditional engineering disciplines: mechanical, civil and electrical.

The First Law may be simply phrased as: *heat and work are mutually interchangeable within a closed system*. Heat can be used to undertake work, and work can (indeed, will usually) produce heat. More elegantly, energy can be dissipated as heat. Even more elegantly: within an enclosed system, the quantity of energy (the total sum of heat and work) is constant.

The phrase *closed system* may have been the vital factor in getting this law recognised, because we do not have any such system, every *practical system* we have leaks energy, work and/or heat, like any government department, and, therefore, setting up equipment to measure the exchange between those two forms of energy is extremely difficult if complete accuracy is targeted.

That leads to the Second Law, generally stated as: *the total entropy of a system increases in any exchange of energy*, easily shown mathematically by referring to the definition of entropy: quantity of heat transferred divided by temperature of transfer, delta-Q over T, which shows the entropy *gained* by the lower-temperature body is greater than that *lost* by the higher temperature body, so the exchange-total has increased.

This author's memories of introducing the word *entropy* to undergraduate classes recalls student reactions that varied from satisfaction to complete bewilderment, the latter coming from the definition of entropy and the former from their accepting that we do not need to know all that, we only need to know how to apply entropy as a useful tool to understand thermodynamic processes. The concept was found to apply particularly when explaining thermodynamic processes graphically to mechanical engineers, who tend to respond so well to pictorial presentations.

One implication of this Second Law is that one can never get 100% efficiency of transfer of heat to work; there is always some loss external to the heat-to-work system. Even the most efficient heat engine, devised by Carnot as a theoretical construct but never built, has a limiting efficiency well below 100%. The other implication is that entropy relates to order/disorder and, because practical systems leak energy from parts with higher levels (such as indicated by temperature) to parts with lower levels, in the long run, the distinction between system parts (if we measure distinction by energy level) becomes less ordered. So, although there are very hot bodies like the sun and very cold bodies like the distant planets, in the very long run, the whole universe may be expected to settle down to the one temperature.

So to the Third Law, which becomes even more abstruse that the above: *every body has a finite positive entropy, but at absolute zero temperature, its entropy may become zero*.

A conundrum is now reached with these laws. The First Law can be readily accepted as a *law*, that is, something that must be accepted because there is no getting around it and there is reasonable experimental proof of it. The Second Law is more difficult; entropy is an artificial item, an intellectual construct, and although one can calculate it from its definition, one cannot *measure* it, hence (a personal opinion by the author) it appears that the second law has not, really, sufficient substance to be termed a *law* – even though it is useful.

The same line of argument applies to the Third Law of Thermodynamics. All one can say is: given the Second law, then the Third Law follows from it. Both are, probably, acceptable as *engineering laws*, but they are not as soundly based as the First, or indeed as soundly based as Newton's three.

These Laws of Thermodynamics have bowdlerised versions that make good sense. The First Law is given as: *you cannot get something for nothing*, which not only rephrases the First Law but is common sense, although there are those in our human population who try (and some succeed) in getting around that. The Second Law has an excessively pessimistic rephrasing: *you cannot get something for anything*, or in gambling terms: *the house always wins*. The Third Law is stated simply as: *everything's zero at zero*, which is, unfortunately, not as dramatic or as telling as the first two. Of those two, the Second Law is met day after day: output never equals input, sad but true. Efforts leak energy; everything runs downhill unless pushed uphill, which does not defeat the system, it just uses more energy.

PARKINSON'S LAWS

The article now moves out of engineering science and hardware engineering into what engineers experience in their work situations. And who better to open this can of worms than C. Northcote Parkinson, with his elegantly infamous (and pointedly true) satires on the British public service.

Parkinson's First Law is: *work expands so as to fill the time available for its completion* [7]. He expanded that to show that a department head will acquire as many subordinates as possible, because the more under him, the more important he/she appears to be, and of course any senior subordinate will acquire sub-subordinates for like reasons, and so on, in an ever-expanding exponential process.

The Second Law is: *expenditure rises to meet income*, which, like the First Law is everyday experience, and both obvious and simple, whether applied to family or government [8]. Private industry may behave more frugally, but as an example of this Law, the author recalls a department head (to whom this author reported in the 1960s) announcing with delight that he'd had a million dollars approved for the year's budget, after which there was a distinct relaxing of previous expenditure constraints.

The Third Law is: *growth leads to complexity, complexity to decay* [9]. This is generally through the onset of complacency.

The Fourth Law is: *delay is the deadliest form of denial* [10]. This is a rephrasing of an older quotation that justice delayed is justice denied.

Two more books by Parkinson are known, and have added to his attack on bureaucracy.

CLARKE'S LAWS

Presented by Arthur C. Clarke, what can best be termed the *Laws of Technology* are given here [11]. Clarke began working life as an engineer-scientist and has a record of some 50 years of writing fiction and non-fiction.

Clarke's First Law is derived from observations of many persons and events in the history of science: *When a distinguished but elderly scientist states that something is possible, he is almost certainly right. When he states that something is impossible, he is very probably wrong*. One of the examples given to illustrate that is Lord Rutherford's claim that obtaining energy from the atom was impossible, even though he was the one who expounded the internal structure of the atom. Five years after his death, the first chain reaction was started in Chicago; unfortunately, he was not around to see he was an example of Clarke's First Law.

Clarke's Second Law is: *The only way of discovering the limits of the possible is to venture a little way past them into the impossible*. This, of course, is the law governing incremental discovery, one person stand on the shoulders of another (using a phrase from Newton) to see further, and so on.

Clarke's Third Law is: *Any sufficiently advanced technology is indistinguishable from magic*. This author's example of that is the imagined occasion of a group of Europeans meeting natives in some previously unexplored territory, say, over a hundred years ago. A native makes a threatening gesture with a spear. A European points a stick at the native. There is a loud noise and a puff of smoke, and a native drops dead. To the natives: magic! To the Europeans: technology. With the wry humour evident in some of his other work Clarke added a footnote: *As three laws were good enough for Newton, I have modestly decided to stop there*.

SCHMIDT AND SIMULATION

Then we have Schmidt's Law of Inappropriate Technology, inspired by reading of a proposal to replace workshop and home economics (including cooking) with computer simulations:

> *A simulation may teach theory beautifully, but unless it incorporated Murphy's Laws in all their glory, it will be far from adequate preparation for using creaky real tools on obstinate real materials* [12].

He went on to remark that:

> *It will not teach safety as it should. There's a profound psychological difference between work in which you run a real risk of slicing off your thumb, and simulated work in which you run no risks at all, no matter how many simulated deadly mistakes you make* [12].

A similar point arose in the second *Alien* movie. One of the soldiers asked the officer how many actions he had been in, and he gave a convincing number. The soldier then asked what sort of actions, and the officer admitted many (or all) were simulations, which led to hoots of derision from the troop.

So: simulations have a place in teaching and in practice, but they do not *replace* live experience.

MURPHY'S LAW

No discussion of engineering, and related education would be complete without mentioning Murphy's Law, which, unlike many of the above (such as Newton and Clarke), lacks a precise origin. There have been references that attribute this *Law* to a real person in the US Air Force of the 1940s, and there are other, seemingly equal citations to evolved common knowledge. Whichever is true is of little import, reference to Murphy's Law has spread through all the disciplines of engineering and is accepted almost as a matter of faith.

The usual phrasing is: *Anything that can go wrong will go wrong.* The reason is simple and based on experiential statistics (to coin what seems to be a suitable term): because of all possible outcomes, 99.999-repeated percent are undesirable.

However, although widespread acceptance has occurred, there is little mention of this *Law* in the literature on risk, accidents, human error and similar items, evidenced by this author checking through the indices of a considerable personal library on these topics. The only mention found was in a recent work by Reason and Hobbs, which quotes this *Law* and takes it as the starting point for error management [13].

No less than 29 corollaries have been seen and only the first is quoted here: When it does go wrong, there will always be someone who knew it would. Indeed, 31 Principles of Adversity have also been found following from Murphy's Law, the one stated immediately after it being O'Toole's Commentary on Murphy: Murphy was an optimist. Two other corollaries are: If it has never gone wrong before: watch it, and: If you have a guarantee that it won't go wrong, watch it just the same.

LAW OF TIME

The old adage, which states time marches on, is well known and accepted, but that is not expressing a law about time. The search for a suitable comment has led back to the author's own work, in which time is given as the fifth management resource, coming after:

> … *Men, Machines, Materials and Money*, and *distinguished by being different. The Time Law is: Time is both non-renewable and limited in total, whereas the others are flexible, even somewhat interchangeable* [14].

Not a Law but a delightful note about time (for any harassed engineer) comes from a musician, Frank Zappa: A composer's job involves the decoration of fragments of time. Without music to decorate it, time is just a bunch of boring production deadlines or dates by which bills must be paid [15].

LAWS OF ETHICS

In a previous article, the author referred to, and used, Asimov's Laws of Robotics to illustrate ethical behaviour [16][17]. They are used here for the same purpose because there seems to be nothing equally adequate to serve that purpose. Asimov's Laws of Robotics are as follows:

- First Law: *A robot may not injure a human being, or, through inaction, allow a human being to come to harm*.
- Second Law: *A robot must obey the orders given it by human beings except where such orders would conflict with the First Law.*
- Third Law: *A robot must protect its own existence as long as such protection does not conflict with the First or Second Law*.

These appear to the author to suggest how humans should behave ethically better than principles such as: *do unto others as you would have them do unto you*. The reverse: *do unto others as others would do to you – but do it first*, is far from ethical behaviour, but may be a more natural human response to adversity and conflict.

AUGUSTINE'S LAWS

Augustine's contribution to understanding what guides human behaviour arose from his experiences with the US Government, dealing principally with government funding [18]. However, many of his 42 laws can be applied to engineering generally, and to project engineering in particular, such as Law No. VII: *The last 10% of the performance sought generates one-third of the cost and two-thirds of the problems*.

Another version of this unhappy state of affairs gave: *The first 90% percent of the project takes 90% of the time; the remaining 10% takes another 90%* – a thought, one might consider, related to Pareto's Law of Expectations, elaborated on below.

Augustine's Law No. XXXI (the Law of Amplification of Agony) is a reflection on Murphy's Law: *one should expect that the unexpected can be prevented, but that the unexpected should have been expected.* Law No. XVI (the Piranha Principle) relates to thermodynamics: *software is like entropy: it is difficult to grasp, weighs nothing, and obeys the Second Law of Thermodynamics; ie it always increases*.

PROJECT ENGINEERING

The fundamental law of project engineering, Cheop's Law, gives: *Everything costs more and takes longer.* The source, probably closer in time to us than Egypt of the Pharaohs, is not available but has been attributed to Pournelle and Posony, and obviously connects with Augustine's seventh law above.

On the subject of project engineering, six phases of a project have been given, and while these may not be quite in the sense of *a law*, they are so close to what can be experienced to be taken as expected in project activity: *enthusiasm*, *disillusion-ment*, *panic*, *search for the guilty*, *punishment of the innocent*, *praise and honours for the non-participants*, to which another writer added: *the rewriting of history*.

LAWS OF HUMAN BEHAVIOUR

There are many features of human behaviour that are so common and so constant that they may well be classed as *laws*, like so many of those cited above. Many of these are phrased as *rules* that should be observed, for example, the Ten Commandments.

Two (much more pragmatic than the above Ten) are provided by Heinlein:

- *Never appeal to a man's better nature – he may not have one – invoking his self-interest gives you more leverage*;
- *Certainly the game is rigged – don't let that stop you; if you don't bet you can't win* [19].

The fundamentals of human behaviour, summed up by Maslow, are related to human needs, which come in five levels: basic, safety, social, ego and self-actualisation (or personal development) [20]. The crux of this is that people are only motivated by unsatisfied needs, once one's social need (for example) is satisfied, it no longer motivates.

Two maxims on dealing with enemies have been found: *always take care of your friends – but first – take care of your enemies* (from the comic strip *Hagar*, by Dik Browne), and from a much more authoritative source, namely Machiavelli: *Be careful in selecting your enemies* [21].

LAW OF ORGANISATIONS

Many organisations, businesses, even government departments, begin small and develop. Are there *laws* that indicate how that growth occurs? Stoner, Collins and Yetton have given the following sequence:

> *A small, young, organisation grows initially by creativity, to experience a crisis of leadership. It then grows through direction (by the new leader) to a crisis of autonomy. Then growth occurs via delegation, to a crisis of control, followed by growth through co-ordination to a crisis of red tape, finally to growth through collaboration* [22].

The Peter Principle presents an inevitable Law of the Hierarchy: *In a hierarchy every employee tends to rise to his level of incompetence* [23]. This is, at first glance, contrary to what one would expect, but on reflection and following the observation of many managers, the author considers it contains a considerable measure of truth.

LAWS OF DECISION-MAKING

Of the many thoughts about decision-making, the briefest and most telling comes from the character Yoda in *The Empire Strikes Back*, who states: *Do or not do. There is no try*.

On a more sophisticated level, two *laws* distinguishing classes of decision-making have been found. The first was offered by John Cleese (in the persona of St Peter, in a training movie about delegation and decisions, titled *The Unorganized Manager*): *If the matter is urgent, deal with it immediately, if it is important, spend as much time as possible getting the right answer.*

The second is from the arch-heretic of management literature, Townsend: *There are two kinds of decisions: those that are expensive to change and those that are not* [24]. Townsend also pointed out there is no point in taking three weeks over a decision that can be made in three seconds, and corrected inexpensively later if wrong.

WARD'S PROBABILITY PROPOSITIONS

These probability propositions arise from the author's research into accidents, and presenting lectures on risk and safety. First, a Murphy-like look at probability: *If the situation you are facing involves your survival, do not trust probability, err on the side of safety*.

The second is an extension of the above, used to point out that trusting probability is two-edged:

> *Maybe the risk of being hit by a vehicle, if you cross a city street without thinking, is only a fraction of a percent. But if a bus hits you and kills you, you are not point-something percent dead, you are 100% dead.*

LAWS OF WHAT TO EXPECT

The Italian scientist and sociologist, Vilfredo Pareto, has provided a ratio that explains what to expect between related-but-different items: the 80-20 rule, identified here as the Law of Expectation [15].

For example, in marketing, it is accepted that 20% of the customers will account for 80% of the sales; in managing people one commonly finds 80% of the headaches are caused by 20% of the people. Actually, the author's experience has suggested the ratio is more like 90:10, but that opinion may be related to knowing the next quotation.

Finally, what better for a last word than an all-encompassing law, which is the ultimate expression of depressed expectations: Sturgeon's Law: *90% of everything is crap* [25]. This has been used by the author to quantify a manager's work-content; 90% (or more) is boring, stifling, irritating and routine, while 10% (or less) is invigorating and exciting.

CONCLUDING COMMENTS

How much of all that can be taken seriously? That is a good question and the only reasonable answer is: the first two pages are *real laws*, the third page can be generally accepted as applying fairly well to the real world, while the final two pages may require some grains of salt before swallowing. But there is some truth in all those last few, perhaps as cautionary tales discovered and told by engineers after a few years of experience in industry and business, even if not as immutable laws *per se*. Look around: there are many more of these.

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9th Baltic Region Seminar on Engineering Education: Seminar Proceedings

edited by Zenon J. Pudlowski, Romuald Cwilewicz & Józef Lisowski

The very successful *9th Baltic Region Seminar on Engineering Education*, conducted at Gdynia Maritime University (GMU), Gdynia, Poland, between 17 and 20 June 2005, was held in conjunction with the GMU's 85th Anniversary and, indeed, the 85th anniversary of maritime education in Poland. Contributions from ten countries are represented in the 50 papers, which include an informative Opening Address about the GMU by its Rector, three Keynote Addresses and various Lead Papers. These papers present a diverse scope of important issues that currently affect on engineering and technology education at the national, regional and international levels. The strong participation from academics at the GMU displays the University's enthusiasm to advancing engineering education for the benefit of students, staff, industry and society.

The paramount objective of this Seminar was to bring together educators from the Baltic region to continue dialogue about common problems in engineering and technology education under the umbrella of the UICEE. To consider and debate the impact of globalisation on engineering and technology education within the context of the recent economic changes in the Baltic region, and in the context of the strong revival of the sea economy, were also important objectives of this Seminar. Moreover, the other important objectives were to discuss the need for innovation in engineering and technology education, and to establish new links and foster existing contacts, collaboration and friendships already generated in the region through the leadership of the UICEE.

The papers incorporated in these Proceedings reflect on the international debate regarding the processes and structure of current engineering education. They are grouped under the following broad topics:

- Opening and keynote addresses
- New technologies and developments in maritime engineering education
- Case studies
- Simulation, multimedia and the Internet in engineering education
- Innovation and alternatives in engineering education
- Specific engineering education programmes
- New trends and approaches to engineering education
- Quality issues and improvements in engineering education

It should be noted that all of the papers published in this volume were subject to a formal peer review process, as is the case with all UICEE publications. It is envisaged that these Proceedings will contribute to the international debate in engineering education and will become a source of information and reference on research and development in engineering education.