On the Use of the Systems Approach to Certify Advanced Aviation Technologies

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Introduction

The field of human factors is as varied and diverse as the human subject itself. But one of its most important applications is the facilitation of safety and efficiency in a particular working environment through the implementation of paradigms known about the human and their working relationship with machines and systems. During the period since World War II (which is often viewed as the birth of Human Factors) no area has been the subject of more human factors research than aviation. And in no time during that epoch is the influence of human factors more important, nor more imperative than it is today.

As technology driven designs have been finding their way into the national airspace system (NAS), there has been growing concern within the aviation industry itself, the Federal Aviation Administration (FAA), and the general public for a means by which to certify complex systems and the advanced aviation technologies that will be responsible for transporting, directing, and maintaining our airborne travel. While it is widely agreed human factors certification is desirable, the philosophy that will underlie the approach is debatable.

There are, in general, two different approaches to certification: 1) the top-down or systems approach; and, 2) the bottom-up or monadical approach. The top-down approach is characterized by the underlying assumption that certification can be best achieved by looking at the system as a whole, understanding its objectives and operating environment, *then* examining the constituent parts. In an aircraft cockpit, this would be accomplished by first examining what the aircraft is supposed to do (e.g., fighter, general aviation, passenger), identifying its operating environment (IFR, VMC, combat, etc.) and looking at the entire working system which includes the hardware, software, liveware and their interactions; then, evaluative measures can be applied to the subsystems (e.g., individual instruments, CRT displays, controls).

The bottom-up approach is founded on the philosophy that the whole can be best served by first examining it constituent elements. This approach would perform the above certification completely antithetically, by looking at the individual parts and certifying good human factors applications to those parts under the basic assumption that the*whole is equal to the sum of its parts.*

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This paper will attempt to form an argument for the top-down (systems) approach, while addressing arguments against it, and pointing out the shortcomings and erroneous assumptions inherent within the bottom-up approach.

Certification

To develop a cogent argument outlining the advantages of the top-down approach to certification, it must first be established what the goals of the certification process are in general, and the certification problems that human factors will attempt to overcome. Certification, in a generic sense, is the process by which a product is declared appropriate for a particular task in that it matches or exceeds a previously defined set of "design to" criteria. In being "certified," it is implicitly understood that the product will safely and effectively perform the task for which it was designed.

Of Aviation Technologies

Certification of advanced aviation technologies involves, many times, the evaluation of products which are technologically new and previously unused or untested. This, in itself, poses an interesting problem because with uncharted equipment the standards by which previous, like, products had been evaluated now become obsolete and inapplicable.

Certification of aviation technologies is also unique from some other certification problems because of the extensive and unavoidable interplay between many systems, so that the systems themselves can be looked upon as subsystems of a larger system. For example, ATC, the fleet of aircraft, and maintenance could be seen as systems unto themselves, but on a larger, more universal scale, their boundaries are not so narrowly defined; each of the aforementioned "systems" are merely players in the entire NAS. Therefore, the certification of each of these interrelated entities by themselves falls, trapped, into the quagmire of "fuzzy" certification, which is neither desirable nor acceptable.

The challenge, then, is to overcome these obstacles. The means for doing so appears to be the implementation of the systems approach to certification. Because the foundation of this theory is built on the premise that the system as a whole is more important than the parts of that system, it could be argued that, by its nature, it avoids the aforementioned problems.

The Systems Approach

A system can be defined (in a broad sense) as the collaboration of functionally similar objects (humans, machines) working towards a common goal within its respective environment. The first and most important aspect in designing any system is to clearly define the goals and objectives of the system (Christensen, 1987; Meister, 1987). In an automobile, the goal is safe, efficient, land travel; in the government, the goal (at least hypothetically) is to serve and protect the citizens; and in the airspace system, the goal is to provide safe, expedient, air transport.

Since the first step in developing a system is the identify the goals, so should the first step in certifying that system be to identify the goals, then certify that system based on those goals.

What Came First: The product or the idea?

Thomas Edison once said that a new invention consisted of "one percent inspiration and 99 percent perspiration." But, the inspiration, the invention's objective/goal, comes first. The first step in developing any system is to first define what the goals will be; it is impossible, if not inconceivable, to begin to build a system without first deciding what it is going to do. The Wright Brothers did not just begin to assemble pieces of wood and paper, only to find out, to their amazement, that the "thing" they built could fly.

Just as the goals of the system are a prerequisite for its development, so should they be a prerequisite for the system's certification. The definition of a system's goals dictates the means by which the certification of the subsequent subsystems should be handled. It seems illogical and erroneous to attempt certification of products without first considering what the ultimate goal of the product is when it is placed in the context of the system.

Starting with the system's goal and working down provides a framework within which an evaluator can examine the parts as contributing factors towards said goal. This eliminates excessive redundancy among components and does not leave room for certain vital components to be left out of the system.

Working Environment

The systems approach looks at the system and the elements of the system in their working environment, and therefore can evaluate the system's ergonomic layout. By this we are referring to the positioning of controls, instruments, displays, etc., within the system and their functional relations to each other. This would be similar to a task analysis, where one wants to examine the physical relationship of functionally similar, and operationally dependent objects in the workplace. This certification is particularly applicable when introducing a new instrument or device into a workstation, in which it ends up being placed wherever an opening is available.

Going from a bottom-up approach, a yoke, for example, could be certified to be poses all of the characteristics of a sound human factors yoke, and it is certified on this criterion, but the evaluation ends there. The yoke, in all of its glory, is not optimally usable if it is placed behind the pilot's seat by the engineers. It is analogous to writing a book of poetry in Egyptian hieroglyphics in the twentieth century; while it may contain brilliant rhyme scheme and flowing poetic prose, no one can read it – it is merely wasted paper. Something is only as good as it is usable.

In contrast to the bottom-up approach, a top-down approach would look at a working simulation of the aforementioned cockpit, and ergonomic problems like the one mentioned above would be recognized. While it is not at all likely that such a huge error would ever come about, the point is still valid, and the problem is still real.

Not only does a system's ergonomic environment need to be considered in certification, but its operational environment needs to be considered as well. By operational environment we are referring to lighting, weather, temperature, etc. The minimum light emittance needed for a display or instrument is directly related to the environment that it will be use in. Therefore it is necessary to evaluate the instrument while in those conditions. This is not easily accomplished through a bottom-up technique, but is easily evaluated within the systems approach.

It could be argued, by the bottom-up proponents, that the product's environment could be replicated during the evaluation to take into consideration the lighting, for example. But, this only really takes care of half of the problem, because another consideration is the light being emitted from other displays, the glare, due to the angle of the display in the system, etc. All of these environmental factors would theoretically be observed in the systems approach through a simulation or mock-up.

Money, Money, Money

The major drivers in any system, whether it be in the developmental, evaluative or production stages, are cost and cost efficiency. The top-down approach is cost effective in two ways: 1) the certification personnel is not required to spend the same amount of time on every product in the system because not every part of the system is forced to meet the same criterion of human factors engineering; and 2) money is saved in the production of the products because of weighted criterion..

Toilet Seats and Tool Boxes. The United States Government was under a great deal of scrutiny in the mid 1980's for purchasing miscellaneous items for its fleet of C-130's (a military transport plane) which appeared to have greatly inflated prices attached to them; some examples were $15,000 toilet seats and $5,000 wrenches. The government justified the purchases by claiming that the equipment had to be "perfect" in order to be usable and safe in their operational environment. While the prices paid for those products were *probably* justifiable (because of the research and development costs for a few production items), it gives insight to problems that could be arise out of bottom-up certification: setting outrageously high standards for a product before its relative importance in the system and the system's environment are known.

If every product in the NAS had to be evaluated by the same standards, the prices for the products would be exorbitant. No one would argue that the toilet seats on a Boing 757 should have to comply with the same human factors standards as the plane's navigation system, to take it to the logical extreme. But, where is the line drawn? How can one judge which products need to pass strict human factors and ergonomic tests, without first looking at its role within the system. The point is that you cannot. As a result, every product, every display, control and widget would be subject to the same meticulous human factors standards. This would result in exorbitant prices for the products which would be felt directly by manufacturers and indirectly by the paying airline passengers.

The systems approach *would* look at the system and the parts that make up that system and do something that the bottom-up approach cannot do: decide the relative importance of each part, and be able to make a well informed decision as to what standards by which they *need* to be evaluated. So, a rarely used, unimportant product does not have as much time and money spent in its certification as a relatively vital, often used product.

In this way, the systems approach would require a reevaluation and alteration of current certification standards. Products should to be evaluated on their functional importance: first, and human factors standards; second, where depending upon the first cause human factors certification may or may not be necessary. For example, if a job required an employee to shovel three pounds of coal from the coal pile to the furnace each day, there would be no need to certify that shovel to optimize ergonomic standards. Any shovel from the local hardware store would satisfy the requirements sufficiently, and to require anything else would be superfluous, and cost inefficient. On the other hand, if the shovel were to be used eight hours a day, five days a week then it should be subject to more stringent encompassing human factors standards.

Workload

One of the main objectives in any human factors effort is to insure a good fit between the humans and the machines they operate. This is done several ways, including personnel selection, training, manning, etc.; underlying all of these processes is an evaluation of the workload incurred by the human while operating the system, whether it be psychological or physiological.

Workload is a very important aspect of any system design, and it is something that must be examined in the certification process. The top-down and the bottom-up approaches address the issue from different angles. The bottom-up approach would look at each part of the system and measure the workload involved with running that particular part. Then by summing all of the measurements, a gauge as to the amount of total workload that would be present in the entire system should be had. The problem with this is that, once again, there should be significant differences with the parts by themselves and with the human's management of those parts when they are incorporated into the system. This method does not take into account secondary tasks. There could be a significantly different amount of workload incurred by the human when they are operating the entire system, than the original guesstimation made; and this number could be either high or low. Since, neither a high nor low workload is desirable because of documented performance deficiencies (Rohmert, 1987), there needs to be a more accurate method: the systems approach.

The systems approach would have the advantage of observing the operator while managing the entire system. Subjective and objective tests could be run to determine the amount of workload, and appropriate measures could be taken to increase the crew, decrease the crew or leave it the same.

Bottom-Up Approach

Several of the problems which are inherent within the bottom-up approach have been described above. In addition to those problems there are others which not only show this evaluative philosophy to be incompatible with certification, but indeed prove it to be undesirable as well.

Inductive Conclusions

It has been argued by many well-respected modern philosophers, including David Hume and Immanuel Kant, that inductive arguments and assumptions can never be validated. The nature of an inductive assumption is that by observing past examples of a particular event, one concludes that: in the future, a similar cause will produce the same effect. For example, if we drop a penny, at time, t_1, and it falls towards earth, it will *necessarily* fall to earth at time, t_2. According to Hume there are no necessary causal connections, and any attempt to predict the future from the past is a fallacious one that it is built on a circular argument. Kant, not as critical, said that there is causality, but we can still never validate a future event based on similar past events.

The process of certification requires us employ inductive logic. We are essentially saying that "if X works now at t_1, then it will work in the future at t_2." Induction is a necessary part of certification and cannot be overcome or circumvented. But the number of times that an inductive conclusion must be drawn can be minimized. As with all necessary evils, the less the better.

Top-down certification must only use inductive logic once: i.e., in certifying that since the system works well during the evaluation, then it will work well in the future (in production use).

Bottom-up certification employs inductive reasoning early as well as later in the certification process, thereby making the probability of error more than twice as great. The human factors certification personnel must not only certify that part X will work when placed in the system – the first case of induction; but, they also must also assume that the system will work when fully implemented – the second occurrence of induction.

Whole ≠ Sum of the Parts

"...Because undermining the foundation will cause whatever has been built upon them to fall down of its own accord." - René Descartes

It does not take an advanced degree in engineering physics to deduct that a house that is made out of bricks could not be built on a foundation made out of straw, without collapsing under its own weight. Basic physics (and common sense) tells us that any physical structure is only as sturdy as the foundation upon which it is built. Similarly, in logic, an argument is only valid if the premises upon which it is "built" are true. If the foundation is weak or the premises are shown to be untrue, the argument crumbles under the weight of invalidity. Bottom-up certification is guilty of being built on a straw foundation.

Bottom-up certification uses as its foundation the premise that the whole is equal to the sum of its parts. While this statement may be true with a jigsaw puzzle, it is certainly not true in certification, nor any scientific endeavour. As far back as Aristotle – one of the first enquiring scientific minds and logicians – it has been recognized that:

> ... We often fall into error because our conclusion is not in fact primary and commensurate universally in the sense which we think we prove it so. We make this mistake when... the subject (element) which the demonstrator takes as a whole is really only part of a larger whole.

In certification terms, Aristotle would be saying that we often err when certifying a part as a entity in and of itself, when it is truly only a part of a larger whole – the system.

Later in *Posterior Analytics*, Aristotle's argument further repudiates the use of the bottom-up approach in certification. It says that while a part can be certified by itself the truth of that certification is only applicable to the part individually; it would not be true universally, because the part is in fact different when it is placed in the system.

With this weakness exposed the foundation upon which bottom-up certification rests is undermined – the theory is invalid.

A Bad Product with Good Certification Criteria

Another, less philosophical, more practical, problem has to do with certification criteria, and the role of the certification personnel in the process. It is conceivable for a product to be valid by human factors standards without being desirable by them. The three-pointer altimeter provides an excellent example (Hopkin, 1994). The altimeter could be certified on the grounds that it provides excellent contrast, brightness and font size. It is judged that it could be visible from every part of the cockpit, and from a performance standpoint it is accurate to +/- 0.5 feet. The problem with this instrument obviously does not within its design, but within the instrument itself.

Incident reports, and experiments analysis of the three-pointer altimeter have shown that is responsible for pilot-induced errors a dangerous amount of times. Misreading of 10,000 feet are not uncommon. Therefore, perfectly sound human factors instrument, is not a good instrument. This once again ties back to the problem of certifying a product, without looking at it in its working environment. In the bottom-up approach, this instrument, could be certified; not to say that it would not in the systems approach, but it is much less likely.

A Portrait of the Artist as a Certifier. To illustrate (quite literally) an error that can occur by using a bottom-up certification process, I will use an analogy: The Analogy of an Artist as Certification Personnel.

Imagine that you were hired out as a professional art certification consultant. This job required that you look at different pieces of art, then certify whether or not they represent what they are supposed to (e.g. an eye looks like an eye; a cow looks like a cow). One of your clients, a not to bright artist, comes to you and asks you to certify an eye for him which he has recently sketched (it looks like Figure 1). The eye looks good – good proportions, proper relationship between the pupil, iris, etc. – so you give it your stamp of approval: A good eye.

Over the course of the next two months the same dimwitted artist shows you another eye, then a nose, and then a mouth, all of which look like what they should represent; again the obligatory stamp of approval given for each feature. Finally, a couple of weeks later he shows you the whole thing, which looks like Figure 2.

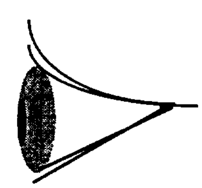

Figure 1. A good eye

The picture is poorly drawn, not because any of the parts themselves are poor, nor because they features are improperly aligned. The picture is poorly drawn because each feature was certified without knowing what the ultimate goal of the painting would be. Each feature, by itself is a good drawing (open for debate), and accurately represents the its respective object. But, when summed together, the whole is wrong.

Figure 2. A bad face.

Conclusion

Certification of advanced aviation technologies should not only pose a unique professional challenge for the human factors expert as a scientist, but also as a consumer, who wants to have the safest air transportation for her and her family. To insure this safety, the best possible method of certification should be employed: the systems approach. This is not to say that the systems approach is infallible, but it certainly is superior to the bottom up-approach. The effectiveness of any certification is only as good as the individual(s) performing it. But, taking human error, or misjudgments out of the picture, the systems approach is more sound fundamentally, practically and philosophically.

It is because of its superiority and not it infallibility that the top-down approach is better suited to certification. David Hume (1977), philosophical empiricist, argued that human judgments and scientific decisions are always made after one entertains two or more opposing arguments, examining the possibility of each by weighing the their relative proofs, then believing the strongest case. "In all cases we must balance the opposite experiments, where they are opposite, and deduct the smaller number from the greater, in order to know the exact force of the superior evidence" (p. 74).

In this situation, the top-down approach provides the strongest case towards its cause; while agreeably it brandishes some problems, the positives highly outweigh the negatives. And from a Humian approach to decision making should rightly be chosen over its counterpart.

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