
Ergonomics and the Development of Agricultural Vehicles

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Abstract. *The development of mechanized agriculture has brought many new features to today's agricultural vehicles. Generally intended to improve productivity and user satisfaction, poor implementation of these features without due consideration of operator requirements and/or limitations can have negative consequences. In order to ensure a successful outcome it is important to understand both the physical and cognitive ergonomics of the system. By understanding these aspects, designs can be optimized for the best outcome in productivity, operator comfort, and satisfaction.*

Keywords: *Agricultural Vehicles, Ergonomics, Human Factors, Occupant Packaging, Usability, Human Information Processing.*

Introduction

While people have been practicing agriculture since the dawn of time, the evolution of mechanized agriculture is a phenomenon of the last 200 years, with the most significant portion of that evolution happening in the last century. As in any industry, that progression has been steady, with occasional leaps enabled by technological breakthroughs. Reduced costs and maximum productivity are clear drivers of progression in any industry and agriculture is no exception.

Similarly, and with humble beginnings in the late 19th century, the practice of ergonomics as a science has grown exponentially in that same time period. Coming from the Greek words *ergon* (meaning work) and *nomos* (natural laws), the International Ergonomics Association dryly defines ergonomics as *the scientific discipline concerned with the understanding of interactions among humans and other elements of a system*. It can relate to physical interaction, such as with tools, machines, and the environment, or cognitive interaction, such as skilled knowledge, stress, and decision making.

In simpler terms, I prefer the statement “if a human is involved, ergonomics is at play.” In that regard, agriculture has always been a human-system interaction. To be sure, it is a complex interaction on both physical and cognitive levels—fertile ground for ergonomics issues, research, and solutions.

I will begin by looking briefly at the evolution of mechanized agriculture and the relevant ergonomic issues throughout. I will concentrate on major technological advances, how they impacted the farmer and farm worker from an ergonomic perspective, and how farm machinery has evolved to meet the ergonomic limitations (or perhaps demands) of the farmer and farm operation.

The goal of this article is to consider agricultural machines through the looking glass of ergonomics, the progression of ergonomics as a science, and its impact on the development of farm and off-highway equipment, both today and in the future. I will explore the different facets of ergonomic science that have implications for today's off-highway products, how they relate to our understanding of the human operator, and how they affect product development.

Finally, I will discuss issues in today's agricultural product development, the relevant tools and methods, and research opportunities for tomorrow.

Ergonomics: Buzz Word or Practical Reality?

The word *ergonomics* may seem to be an over- or inappropriately-used term at times, but the practical reality is that a good understanding of ergonomics and human interaction is a necessity for any successful product.

In practice, the root of many product complaints can be related back to an ergonomic mismatch. A product that has not adequately considered the needs of its users will invariably face market headwinds, if not complete failure. It is unfortunate to take a negative point of view, but while good ergonomics is not necessarily the motivating factor in a decision to purchase a product, poor ergonomics can definitely be a reason *not* to purchase. Put simply, a positive product ergonomics outcome does not always receive direct praise on a market level, but negative ergonomic outcomes are invariably a high risk to any product's success.

To understand how ergonomics relates directly to product development in the off-highway industry, let us consider the industry as it has evolved to the present day.

Evolution of Mechanized Agriculture

According to the National Academy of Engineering, the mechanization of agriculture is considered one of the top ten engineering achievements of the 20th century. From tractors, to combines, to pivot irrigation, the evolution of agriculture in the 1900s was rapid.

The most interesting fact in NAE's assessment of this evolution is in the reduction of labor. In 1900 farm labor represented 38% of the nation's workforce. As the century drew to a close, that number was approximately 3%. Similarly, from 1940 through the latter half of the century, USDA figures show the number of people fed by a single farmer grew from 19 to 155. This increase in productivity would have been simply impossible without the technological advances of mechanization.

The following list highlights that development along with a brief discussion of the related ergonomics issues (adapted from NAE, 2011).

1901 *Hart and Parr open the first US factory dedicated to the production of internal combustion powered traction engines.*

- Much like Ford's Model T production line, this marks the beginning of the "tractor" industry as we know it.
- Tractors are the most essential part of modern, productive farming, providing mechanical traction power to all aspects of farming activity.
- The ergonomic implications are simple—we begin a mass shift from farmers and farm hands "laboring" to "operating," letting the machines do the actual work while the operators control.

1922 *International Harvester introduces the power takeoff.*

- By transferring the engine's rotational power to an implement, rather than relying on ground speed drive, the implement's productivity can be markedly increased.
- The ergonomic implications of the PTO definitely center around safety.
- The rapidly spinning shaft can quickly entangle clothing and/or limbs causing serious injury and death.

1931 *Caterpillar introduces the diesel-powered crawler tractor.*

- Still the preferred fuel of modern day tractors, diesel fuel is safer to handle, and enables a system with better power, torque, reliability, and fuel efficiency.

1932 *An Allis Chalmers tractor in Waukesha, Wisconsin, is outfitted with Firestone Aircraft tires.*

- The Nebraska Tractor Test Laboratory finds a 25% improvement in fuel economy.
- Tractors are now capable of traveling at speeds in

excess of 30 mph, improving both in- and out-of-field productivity.

- Ride comfort is an immediate ergonomic benefit to the operator, along with lower wear and tear on the machine itself.

1933 *Harry Ferguson develops and implements his hydraulic draft control on a tractor.*

- This is a watershed moment, unleashing the power and versatility of hydraulics on agricultural tractors and implements.
- Ergonomically, the implications of hand controls beyond drive and PTO must now be considered.
- Due to the need to act directly on the hydraulic valves, some ergonomic compromises are required.

1938 *Massey-Harris introduces the world's first self-propelled combine.*

- The reaping, binding, and threshing technology advances of the previous 70 years culminate in the self-propelled machine we recognize today.
- Marked productivity increases result from "combining" multiple harvest steps into one machine.
- The most significant ergonomic benefit is the major reduction of material handling by farm hands. Ergonomic issues include visibility and optimization of machine performance for maximum productivity with minimal grain loss.

1966 *DICKEY-john applies electronic sensing and monitoring to planting and seeding equipment.*

- This is a precursor to the widespread application of electronic control and monitoring in today's agricultural equipment.
- Electronic sensing and control now moderate most functions in modern agricultural equipment, from electro-hydraulic remote valves to automatic climate controls.
- The advent of electronic controls has enabled large improvements in ergonomics by allowing optimum ergonomics to drive control designs, rather than mechanical needs.
- The reduction of control forces reduce or eliminate physical operator fatigue, while electronic mediation enables optimal performance while preventing accidental or intentional misuse.

1994 *Farmers begin using GPS (the Global Positioning System) as a tool in their operations.*

- GPS enables such technologies as automatic row guidance, as well as yield monitoring and selective input application.
- GPS, in combination with electronics, enables technologies such as self-driving autonomous vehicles, practical yield monitoring, and prescriptive application.
- Ergonomic improvements are centered on perfor-

mance, enabling operators to concentrate more attention on implement/machine performance instead of driving.

- Ergonomic issues are lack of operator attention and inappropriate reliance on autoguidance.

2000s *Multi-function, touch screen displays, CAN and ISO bus.*

- CAN bus provides a unified protocol for machines to distribute electronic instructions and feedback between different parts of the vehicle.
- Reconfigurable displays provide greater flexibility for operators to interact with machine functions and monitor performance. From one single location, operators now have the ability to set and review multiple machine parameters, as well as view readings of machine and/or implement performance.
- Cognitive ergonomics, information processing, and situational awareness become almost as important as physical interaction with the machine.

Present Day

In the development of today's complex off-highway machinery, the inclusion of human factors and championing the operator's needs has never been more important. Fundamentally, off-highway machinery has been the same for last few decades—tractors, combines, sprayers, tillage equipment, etc. But while we have developed the same machine types for some time, the content in those machines is increasing with each successive iteration.

As technology advances, a greater number of features are incorporated. This is driven as much by seemingly unrelated technology as much as it is by pure research and advancement in farming. Excellent examples of this include the advent of mobile telephones and GPS. We would initially think these two technologies have little application to the practice of agriculture, and yet the ubiquity of the cell phone and the contributions of GPS to efficient production agriculture are well accepted phenomena.

The human factors considerations for those new developments are endless. The more complex a system is, the more complex human interaction with it becomes. As an industry we have begun considering more human limitations, such as situational awareness and the potential for operator mental overload created by these ancillary technologies. Even ignoring those, machines are simply more complex today than they once were. New farmers take for granted things like touch screens and electronic controllers in their machinery, while their parents and grandparents who started farming 20, 30, 40 years ago could never have anticipated these essential parts of modern, productive machinery.

Sometimes electronic control mediation and automation can help mitigate the impacts to operators, but if the human capabilities are not addressed or understood properly, the opposite can happen: loss of awareness, cognitive overload, and the resulting decreased human-machine performance.

At the same time, as technology in our day-to-day lives has developed, the field of cognitive ergonomics (the understanding of human information processing) has taken a more prominent place in the design of equipment and systems. As the cliché goes, we live in a society where information is power, and that is equally true in the development and day-to-day use of the products we develop. How people *use* machines is just as, if not more, important than how people fit in machines.

I will discuss the cognitive impact of technology on operators later, but for now will examine the modern integration of physical ergonomics to today's products.

Physical Ergonomics in Modern Product Development

The science of drawing and drafting in multiple 2-dimensional projections to convey what is ultimately a 3-dimensional part or system is dead. Until the early 1990s, I probably would have been held in blasphemous contempt for that statement, but we now live in a 3D world, developing 3D parts of 3D systems. The advancing power, decreasing size, and increasing affordability of computing (and more specifically desktop computing) that began some 20 years ago has fundamentally changed the product development process

Up until the mid-1980s it was not uncommon to see rows and rows of drafting tables in any of the major equipment manufacturers' engineering centers. Today, that scene has been replaced by simple desks and cubicles with personal computers.

In the early times of CAD, such as the 1960s and 1970s, only the most powerful companies with the deepest pockets had the ability practice computer aided design. Major companies in aircraft, defense, and automotive, such as Lockheed, Boeing, General Motors, and Ford, were pioneers in CAD and product development (Blanchonette, 2009). In many respects some of these companies influenced the evolution of CAD just as much (if not more) as CAD did their processes.

And just as we exploit computing power to perform analysis and simulations on proposed designs, we now also exploit that power to perform analysis of a product's ergonomics.

Digital Human Modeling CAD

In the late 1980s and early 1990s, a number of independent groups of academics and researchers in ergonomics were exploring ways to harness the increasing power and capability of computers. As with development of CAD itself, the leaders in Digital Human Modeling CAD or Computer Aided Ergonomics research were closely related to defense, aerospace, and automotive development.

Even before that time, Boeing pioneered some of the first Computer Aided Ergonomics tools with the development of

their First Man digital manikin later known as “Boeman” (Blanchorette, 2009). The basic premise at work was that human size and capability across a population can be quantified and modeled. In so doing, those capabilities could also be computed or modeled dynamically using computers.

In the 1980s, development of the Jack system at the University of Pennsylvania and systems such as SAMMIE CAD at the University of Nottingham and Loughborough University in the UK ushered in a new era of accessible digital human modeling. Computer Aided Ergonomics had now moved from mainframe to desktop, running on Sun SPARC or Silicon Graphics and later PC systems. They are considered the progenitors of modern physical ergonomic design tools. In fact, the Jack system continues as one of the most widely used digital human systems.

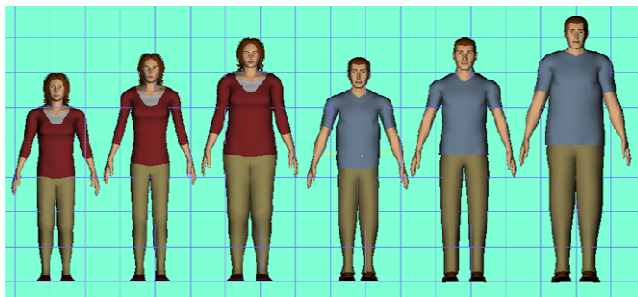
Today, those past works have manifested into a number of highly dynamic ergonomic computing tools including Human Solutions’ RAMSIS, Siemens’ Jack, the University of Michigan’s 3D SSPP (Static Strength Prediction Program), and many others.

The industrial and military vehicle sectors in particular use Jack as a preferred digital human model. CNH, John Deere, and Caterpillar all use Jack today, as well as our friends in the trucking industry (with similar ergonomic environments), International Truck and PACCAR.

No matter which digital ergonomics platform is used, these tools provide us complete digital humans to insert to our digital environments and allow us to explore an infinite number of ergonomic scenarios, including different human shapes, sizes, biomechanics and strengths—virtual humans for virtual products.

Figure 1 shows an example cadre of humans from the Jack digital human system. Note the variations in gender, height, mass, and proportion.

The advantage of this tool and its anthropometric size, strength, and perceived comfort databases, is it allows the ergonomist to explore a variety of ergonomic situations including the extreme variations in human size that exist in a global population. The models are data driven from true empirical data and the ergonomist can be confident that the result they obtain closely simulates what the actual situation will be once the product is produced.



**Figure 1. Cadre of Jack manikins
(from Jack, ver. 7.0, Siemens, 2010).**

Occupant Packaging and Virtual Ergonomic Validation

Once a virtual product begins to take shape in the 3D CAD environment, we can immediately begin to digitally validate its ergonomics. There are several ergonomic aspects which can be virtually assessed using the 3D data, but generally the most important of those is the occupant package: where the operator is seated, and his or her comfort and ability to reach the controls and see what’s required.

The concept of packaging, while practiced in other industries, evolved as a science in the automotive industry. The basic drivers (pun intended) of operator comfort are generally considered to be floor location, seat position, and pedal and steering wheel placement. In most cases, this means fixed-position pedals and floor, and adjustable seat and steering wheel.

In off-highway equipment we have the added complexity of a seat that floats up and down due to its suspension. And so it behooves us to use a central point to relate all other items back physically to the operator. This magic point is called the Seat Index Point or SIP.

Prescribed empirically by ISO 5353 (ISO, 1995), the SIP is theoretically the center of the hip joints of a 50th percentile male operator, in a given seat, in mid travel fore-aft and up-down. As the central accommodation point of any occupant package and prescription of where the operator is located, it is used for evaluating and designing items beyond the basic occupant package, such as operator rollover protective structures and assessing visibility as the root of theoretical eye points. If an item relates to the operator, the SIP is the base starting point.

This approach forms the ideal foundation for a good ergonomic design because it is naturally operator-centric.

Inside Out

In the late 1990s, Porter and Porter (1998) coined the phrase “inside-out design” as an approach to occupant packaging in automotive applications. Essentially we begin with the human (or humans) of the target population and their physical characteristics and we begin to build outward from there.

Porter’s design study at the time was a simple two-seat, mid-engined sports car that could be easily enjoyed by two large male occupants. The design brief was challenging: weight less than 500 kg, cost less than 10,000 Pounds, and able to be built in 20 months. Essentially, what Porter was demonstrating was even with the tightest of constraints for weight, size, and cost, one could still have a successful ergonomic outcome.

Many readers will recognize the sports car in question as it became known as the Ariel Atom.



Figure 2. The Ariel Atom (retrieved from www.digitaltrends.com/lifestyle/ariel-atom-3/).

Figure 3. Seat, SIP, and ISO 4253 zones.

With Porter in mind, it is easy to see that most constraints on ergonomics in off-highway equipment could be considered imagined. Most of the products in our industry are far larger than this small car. In this context, most arguments for physical constraint of the occupant package of an industrial vehicle evaporate. In other words, there is no practical barrier to developing an ideal ergonomic package on any product in this industry. Take your SIP, decide on the human characteristics you must accommodate (height, mass, etc.), and build the vehicle around the operator.

In agricultural products, the heavy lifting of this initial occupant packaging is covered quite concisely by ISO 4253 (ISO, 1993), which prescribes the relationship of pedals and steering wheel to floor and SIP. Figure 3 shows an example seat, the SIP point on the seat, and the ideal placement zones for the steering wheel center and pedals at rest. Figure 4 shows a digital manikin inserted into the same environment.

From this point we start to consider the more complex physical interactions—comfort zones, control reach, visibility, accessibility, etc. Criteria for those can be standard, regulatory, and/or proprietary, but the approach is the same regardless of the source—we start with the user and work our way out.

Figure 4. Human inserted to SIP showing ISO 4253 zones.

User Centered Design: An Idealized Approach

As discussed above, ergonomics is the integration of human needs and wants into a larger system. As with any design philosophy there can be extreme approaches to each. Vincente (2003) discusses these in terms of mechanistic and humanistic points of view. The mechanistic-minded designer takes a system or product-centered view of development, while the humanistic designer places the operator needs above all else in a system. In reality, neither approach is practical in successful product development. Ergonomics is a science of compromise, seeking to please the greatest number of users under a set of fixed constraints.

Pheasant (1998) described an approach to user-centered design that is a bit more practical. Its principles are rooted in understanding that a user has needs within the context of a system, but that systems are developed under constraints that aren't always practical to change. This user-centered design philosophy is generally accepted today as the basis for a good ergonomic outcome. It applies universally to just about any human-machine system and applies equally well to both physical and cognitive integration of human systems ranging from the most simple to complex. These prin-

principles are adapted from Pheasant and summarized below.

1. *User-centered design is empirical.* We must base our design decisions on hard data. Human behavior and characteristics are observable, which means they are quantifiable and we must seek to base our decisions on well-collected, relevant data.

2. *User-centered design is iterative.* Product development is cyclic. Our data-driven designs must be evaluated for outcomes which, in turn, provide more empirical data for refinement.

3. *User-centered design is participative.* It seeks the input of the potential end users and considers them as active participants in the process.

4. *User-centered design is non-Procrustean.* In ancient Greek mythology, Procrustes invited passers-by to try his bed of arbitrary size. If the subject did not fit the bed, Procrustes would amputate the limbs in question to fit. User-centered design considers the characteristics of people as they are and aims to fit the product to the user rather than vice versa.

5. *User-centered design takes account of human diversity.* It seeks to find the best possible match to the greatest number of users.

6. *User-centered design takes account of the user's task.* It recognizes that a match between a user and product is generally task-specific.

7. *User-centered design is systems-oriented.* Any interaction between a product and user takes place within the context of a larger system providing its own constraints. These constraints can be economic, political, monetary, regulatory, environmental, or any combination thereof.

8. *User-centered design is pragmatic.* In most cases there are limits to what is practical. It seeks to achieve the best possible outcome within these limits.

The practice of modern ergonomics in a product development environment does not just favor, but demands an approach such as Pheasant's. Pragmatism is the key, developing the best product possible within the typical temporal and economic constraints of a process.

Discussed in physical terms above, the user-centered philosophy has equal applicability to cognitive interactions.

Cognitive Ergonomics, Human Factors, and How We Use the Products We Make

It is impossible to discuss human interaction with a product or system on a solely physical level. People also interact with their products and environments on a cognitive level. From simple opinion to situational awareness of a complex system, the understanding of human perception, mental models, and limitations is essential to a successful outcome.

As ergonomists, we generally consider the way in which users interact with a system on an operational level. How-

ever, there are a number of ways that people relate to products on a mental level. Those can be divided into two main groups: perception of the product and operation of the product.

Product perception:

- Aesthetic pleasure or styling perception
- Perception of quality: materials, construction, durability, reliability

Operation:

- Control identification
- Usability or ease of use
- Perception of complexity
- Fitness for task
- Information presentation
- Situational awareness

In any human machine relationship, any or all of the above are given consideration by the user and these considerations can be implicit or explicit. The role of the ergonomist in optimizing this relationship is to maintain understanding of users' perceptions and limitations as they relate to the stimuli and ensuring these are adequately understood and considered by the engineering team.

Brand and Product Perception

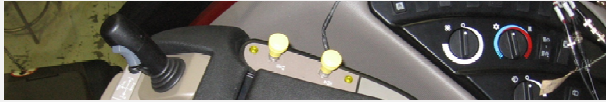
Human perception of the environment is a psychophysical phenomenon. This means that stimuli presented to an operator are physical in nature (auditory, visual, touch, smell) and these physical inputs impart certain psychological effects. Depending on the nature of the physical stimuli, the psychological effect can be positive, neutral, or negative.

Martin Lindstrom explores this idea even further in *Brand Sense* (2005), considering these psychophysical relationships as being inherent to the brand's identity. We generally think of brand as a visual trait, but in the context of ergonomics, any physical interaction with a product can also have a brand relationship or message.

Certain brands have traits unique to them; steering wheels provide examples of how things can look and feel. However, some product traits are cognitive or have to do with "how" they operate. Some may consider these idiosyncrasies, but brand-loyal customers consider these ergonomic traits as essential to what makes their brand work for them, so much so that this can be how they describe what makes a Brand X product a Brand X product.

Let us consider the two examples below. You can see very quickly that ergonomics is directly related to the product's user experience and, consequently, its brand identity. The short list by each figure highlights some of the significant control differences.

While the two systems are strikingly different, they each represent the respective brand's control system for the same class of tractor. They *are* the ergonomic control DNA of their brand.



- Moveable multi-function handle integrates hand throttle with multiple primary controls
- Monochromatic remote valve controls identified by number and spatially arranged to mirror the position on the back of the tractor
- Secondary controls located on a flat horizontal panel at the base of the armrest cushion
- Functionally grouped secondary controls panel in color coded zones
- Smaller, toggle switch-type PTO controls
- Rotary knob hitch position control

Figure 5. Case IH MultiControl armrest.

- Fixed multi-function handle with primary controls
- Separate hand throttle
- Color coded remote valves
- Secondary control panel rising from the side facing the operator with integrated hand hold
- Metaphoric tractor layout with secondary controls placed in their true location on the tractor graphic
- Large, mushroom-type PTO controls
- Pommel-shaped hitch control with linear slider position control.

Figure 6. New Holland Sidewinder II armrest.

Perception

At times, the psychophysical relationship blurs the lines between physical and cognitive ergonomics when it comes to product perception. Take, for example, a door handle. Aspects such as shape, location, and force are physical phenomena, but that door handle as a package will have a psychological perception to an operator. In most cases this perception will be neutral. A door handle is a door handle. In some cases, though, it will have a distinguished, positive perception, perhaps due to soft-touch materials or a light force. And in many other cases that perception could be negative, perhaps due to inadequate size, poor placement, and/or a high operation force. Lindstrom professes exploiting the positive perceptions across a brand to maximize the brand's association with pleasing physical traits. We use good ergonomics not only to enhance the perception, but we exploit it as part of the product's identification—it's not just the ergonomics DNA, it's the *brand's* DNA.

Information Processing

Returning to the concept of “how” we operate machinery, let us consider the information-processing aspects of product use.

Humans perceive information constantly from the environment. The information is presented in many different modalities, most importantly visual, but also auditory and tactile. The information is coded and processed by the human as input to short term or long term memory. In turn, processing results in a decision to act (or not) and an action is taken by the person.

Day-to-day interaction with a vehicle is definitely a processing task. The operator receives constant information input from the vehicle and makes decisions based on those inputs to execute actions. Take simple driving. The operator is performing a primarily visual task (tracking a vehicle on a desired trajectory) by taking the information input, processing the performance, and acting in return on the system to modify the outcome (maintain or change direction, speed, etc.).

The implications for performance become most relevant when the operator's mental workload approaches their capability limits. When multiple tasks begin to compete for the operator's attention, he or she can become overwhelmed, resulting in decreased performance or, worse, accidents.

Operators of off-highway vehicles are excellent multi-taskers. By nature, they must perform a number of concurrent tasks, such as driving plus implement operation, or in the case of a harvesting application, driving plus machine optimization. But, just like any other dynamic task, if the operator is presented with too much information (or more than can be processed effectively), performance degrades. This can be as simple as going off a row while combining corn or as devastating as running over a fellow worker.

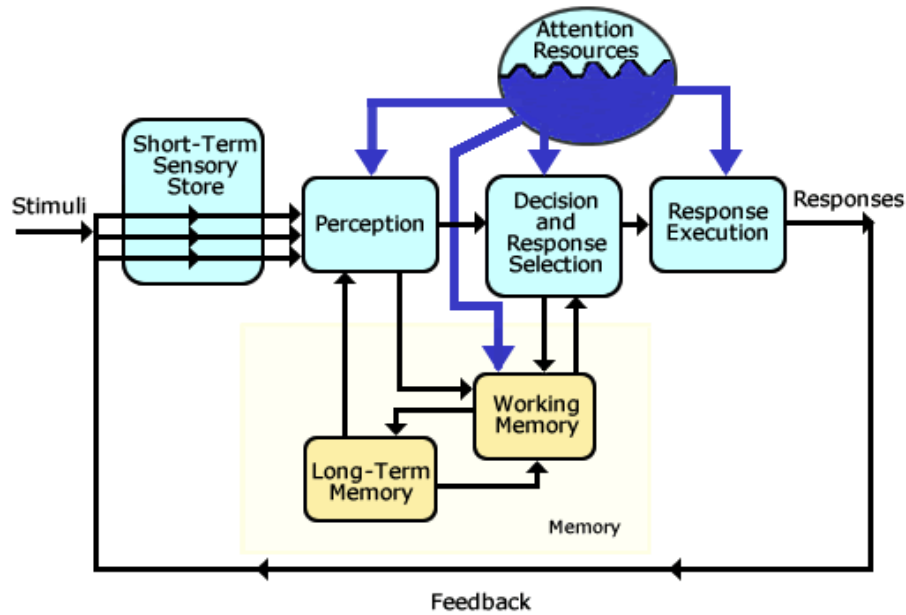


Figure 7. Wickens' model of information processing (retrieved from www.hf.faa.gov/webtraining/Cognition/CogFinal008.htm).

This cognitive overload phenomenon was examined by Wickens (1992) and is described by his general model of human information processing (fig. 7). The central feature of Wickens' theory is that we process information in stages and each of those stages is mediated by the amount of attention we are able to devote to it.

Fundamentally, we have a fixed amount of attention to give and when that resource is exceeded, operator (and system) performance declines.

So, How Much Is Too Much?

Most machinery operation tasks would be considered by Bridger (1995) as short term memory (STM) processes. They involve perception, decision, response selection, and response execution, all mediated by the available attention. The significance of this is threefold: there is a limited storage capacity to STM, the retention interval is short, and the information decays over time or becomes displaced by new information.

Short Term Memory Characteristics (Bridger, 1995)

Capacity:	7 items ± 2
Retention time:	5-30 seconds
Mechanism of loss:	Decay or displacement

Consider the above characteristics and examine Figure 8 (next page), which shows an information feedback screen from a combine harvester.

Figure 8 is one screen of six screens which can be accessed by a combine operator. The one seen here presents no less than 25 individual bits of information (not including the icons themselves), each with a varying degree of interest to the operator, who is also driving and operating the

harvesting controls. Some of the information bits are categorized here.

Frequently viewed:

- Grain loss monitors on the bottom—To ensure maximum threshing performance and clean grain without loss.
- Engine load—To ensure maximum use of the power available.

Occasionally viewed:

- Rotor speed/fan speed—To assess mechanical performance/problems.
- Yield and moisture—To determine crop quality throughout the task field.

Seldom viewed:

- Header height, fuel level, coolant temperature—For reassurance that system is operating normally.

There are a number of ways that operators will divide their attention to manage their information processing. Usually it is temporal division (of necessity, the information is all being accessed at different times, not all at once), but it can be divided in other ways.

Another popular method of information division is by input modality... we don't have to input all that information visually, we can present it in other modes, such as auditory or tactile. Because the amount of attention that an operator can use to focus on a given input modality is limited, it is possible to allocate greater amounts of attention if you split the presentation over different sensory inputs. This enables better multi-tasking.

A simple example would be driving a car and reading a book. They are both primarily visual tasks competing for

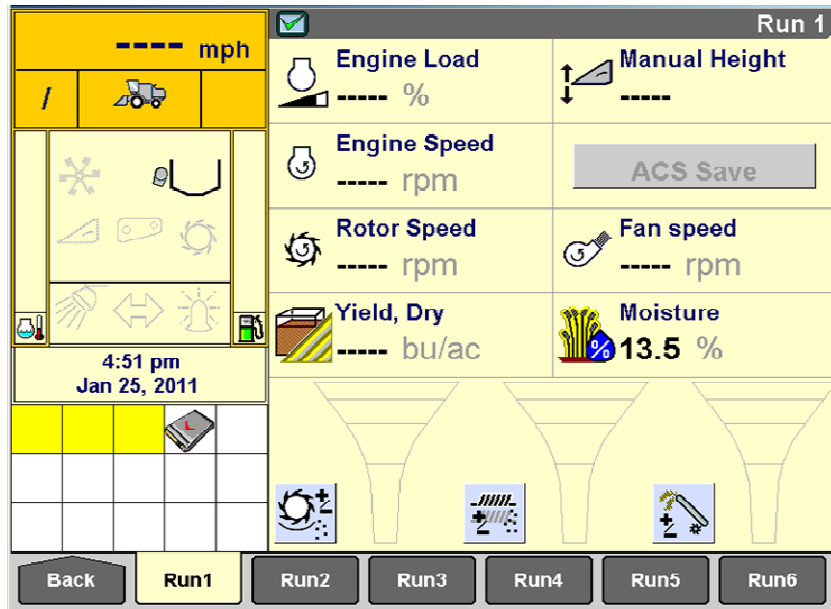


Figure 8. Combine “run” screen. (© CNH America LLC 2012 all rights reserved. The colors, designs and configurations appearing on the touch screen are a trademark of CNH America LLC.)

visual attention. The ultimate result is a negative outcome. Change the input modality of the book’s information to auditory and the result is much different. Suddenly you can easily drive and absorb an audio book’s information with relative mental ease. Same driving task, same verbal information, differing outcomes.

In the case of machine development, we already exploit this. During the visual task of operation, it is not likely that an operator will perceive warning lamps in a temporally efficient manner, especially if their attention is primarily allocated to the operation at hand. So, warnings that require immediate attention also have associated auditory feedback in the form of buzzers, bells, or beeps.

Although there is no strict limit to the number of items that an operator can process, a limit will always exist and vary based on task, operator skill, and system design. Your goal as an interface designer is to present the information coherently and concisely so that it requires the minimum amount of attention possible to process. This allows the perception of each information bit to occupy as little time and resources as possible, allowing the operators to concentrate their remaining attention on the primary task of operation.

Here is a small sample of current technologies that allow operators to multi-task more efficiently:

- *GPS autoguidance.* Eliminates the visual tracking task of driving, enabling the operators to focus visual attention to other items, such as implement control, or even factors outside the system, such as the weather, markets, etc., via smartphone or PC.
- *Automatic height control (combine header or implement depth).* Positional sensors provide feedback to the system directly to automatically control the ma-

chine’s working height, reducing the mental workload of the operators.

- *Automatic crop settings.* Current sensing technologies and feedback algorithms enable the machine itself to determine its performance and make closed-loop adjustments to maximize productivity or product quality. This reduces and can even eliminate the need for operators to be concerned about the system’s outputs. Alternatively, this allows larger operations to use less skilled labor while maintaining ideal machine performance.
- *Telematics.* Large fleet operators can remotely and concurrently monitor their fleet, assessing performance, maintenance requirements, and diagnosing system failures.

Many of today’s technologies also enable improved productivity from a physical ergonomic point of view:

- *Vehicle, cab and seat suspension.* By reducing physical inputs to the operator, suspension enables greater travel speeds and longer work periods. This translates to increased productivity.
- *End-of-row automation.* By recording and replaying repetitive control sequences, the operator does not have to physically hit each switch. This not only reduces operator movement and fatigue, but ensures consistency and repeatability of performance. Less control input mistakes mean more efficient operation and consistent results.

Why?

So the burning question is why are we paying attention to ergonomics? Why would a company spend precious re-

sources in consideration of good ergonomics? The answer is quite simple. Good *ergonomics* = good *economics* (Hendrick, 1996). Better ergonomics means increased comfort, safety, and productivity, which in turn equals increased profitability for our customers.

Good Ergonomics = ↑ *Comfort, Safety, and Productivity*

therefore

Good Ergonomics = ↑ *Profitability*

The best possible ergonomic match maximizes an operator's effectiveness, comfort, and system safety. For every ergonomic mismatch, you are deducting from your ideal productivity, costing time and/or money.

For the manufacturer this is a tangible thing—something that differentiates you from the market and provides real-world value to your customers.

Skeptical? Ask the farmer who gets a sore back from an improperly designed seat. Ask a combine operator who has to crane forward and strain his neck because the visibility to the header is suboptimal. Ask the farmer who spends two hours trying to figure out how to properly set up a planter touch screen. They're all losing productivity and suffering aggravation, both physical and mental, and the root causes of their frustrations are all ergonomic in nature.

Concluding Remarks

It is obvious even to the casual observer that human interaction with off-highway products can be a complex subject. The implications of this interaction can be studied on both physical and cognitive levels, but the interaction, as a whole, crosses both disciplines.

Modern ergonomic technique uses vast amounts of research and data and applies very accurate tools for assessing human physical interaction with machines. This saves large amounts of time, and human and economic resources, by identifying and addressing ergonomic problems earlier in the design cycle than ever before.

By considering the needs and capabilities of operators from the outset of a design, the process can be guided to achieve a successful ergonomic outcome. Advances in concurrent engineering and virtual evaluation enable more relevant and realistic simulations to be conducted and engineers to anticipate ergonomics issues on a virtual basis, before a machine is physically built.

The most pressing issue in off-highway ergonomics today is cognitive rather than physical in nature. As feature sets expand, operators are presented with ever more information regarding system performance, which they are required to process and act upon for the most successful outcomes. The challenge for today's product ergonomists is regulating information to that which is necessary to complete the task at hand and presenting it in a cohesive, usable format.

Future development in off-highway vehicles will cer-

tainly need to consider remote and autonomous operation. The human implications of these on a physical level are remarkably different; however, the theories of information presentation, situational awareness, and mental workload and overload still apply. Just as other aspects in vehicular ergonomics have benefited from research in aircraft and military applications, the development of remotely operated military aircraft has made positive contributions to the ergonomics literature, sharing many of the lessons learned, which have a high degree of applicability to off-highway product development.

The role of good ergonomics in successful off-highway product development cannot be understated. Highly skilled operators, performing complex tasks, using complex machines are the norm rather than the exception. Their success depends on vehicles that not only provide for their physical ergonomic needs but also suit their intended task and performance goals.

Ergonomists and their understanding of human capabilities and limitations are the natural link between those skilled operators, the tasks they wish to perform, and the development of products that bridges the two.

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