A Mathematical Equation for Quantifying Control Functionality in Agricultural Tractors

by

Dimitrios Drakopoulos

A Thesis submitted to the Faculty of Graduate Studies of

The University of Manitoba

in partial fulfilment of the requirements of the degree of

MASTER OF SCIENCE

Department of Biosystems Engineering

University of Manitoba

Winnipeg

THE UNIVERSITY OF MANITOBA

FACULTY OF GRADUATE STUDIES

*****

COPYRIGHT PERMISSION

A Mathematical Equation for Quantifying Control Functionality in Agricultural Tractors

by

Dimitrios Drakopoulos

A Thesis/Practicum submitted to the Faculty of Graduate Studies of The University of Manitoba in partial fulfillment of the requirement of the degree

of

Master of Science

Prayer

I offer you tonight, Lord, the work of all the tractors . . . in the world.

Prayers of Life: Michel Quoist

Table of Contents

Acknowledgements

My acknowledgements will really have to be divided into two halves. The first half is dedicated to acknowledging everyone who helped me during my graduate student career at the University of Manitoba. First of all, I would like to thank Dr. Danny Mann for his insight, direction, and patience during my time at the University of Manitoba. I would also like to thank Dr. Margaret N. Friesen and Dr. Ying Chen for their insightful comments.

The second half of my acknowledgements is dedicated to my parents, Martha and Panagiotis, who have been the most significant persons in my life. Without your support, persistence, and love I would not be where I am today. Your words and actions are inspiring to me. Thank you!

List of Tables

List of Figures

Abstract

Author: Mr. Dimitrios Drakopoulos

Title: A Mathematical Equation for Quantifying Control Functionality in Agricultural Tractors

(Under the direction of Dr. Danny Mann)

Efficient operation of a machine depends upon the design of its control layout. Well–arranged controls, whose operational characteristics are based on design standards and on human factors considerations, allow the operator to easily assess and operate them maximizing the operation performance. Any new idea for ergonomic improvement of the layout can be applied if it is in accordance with the design standards, but the problem of the overall ergonomic assessment still remains. The objective of this thesis is to develop a numerical index, referred to as an 'Index of Functionality', capable of comparing, on a mathematical basis, different control arrangements in agricultural tractors. The model is based on information that has been gleaned from the published literature, with input from both professional ergonomists and experienced agricultural tractor operators. With the inclusion of factors related to controls of tractors, the model can be used to assess the degree to which tractors' controls are compatible with the expectations of the operator for easy, efficient, and convenient operation. To validate the model, data collected from a total number of six old and six modern tractor workstations to determine its capability to recognize improvements that have occurred in the ergonomic design of tractor control layouts over the past 20 years. Results showed average value of 0.71 out of 1 for the modern tractors and 0.20 out of 1 for the old tractors. The difference between the two average values confirmed the fact that the 'Index of Functionality' is an effective 'tool' which clearly recognized the latest ergonomic improvements in tractor workstations over the past 20 years.

Keywords: *Tractor workstation, Control access, Control placement, Ergonomic evaluation.*

1. INTRODUCTION

The term human factors is used to describe the abilities, limitations, and other physiological or behavioural characteristics of humans that affect the design and operation of tools, machines, systems, tasks, jobs, and the environment. By careful consideration of human factors it is possible to achieve user–friendliness, convenience, effectiveness, efficiency, and increased productivity. Also, one can enhance desirable human values such as improved safety, reduced fatigue or stress, increased comfort, greater user acceptance, increased job satisfaction, and improved quality of life.

Most machines work in coordination with people. An interesting example is the consideration of the types of interactions between a driver and a tractor. First, by entering and sitting in a tractor cab the operator occupies a workspace around the seat. During operation, he has to move in this space to reach the various instruments and, therefore, an enlarged workspace is occupied by his reaching movements. Second, based on information received by the sensory inputs, the operator acts as a controller. For example, he determines how much engine power to provide and in what direction to keep the tractor under control. Third, the operator acts as a sensor, listening to determine if everything is functioning properly, seeing where he is going so that he can guide the tractor, and feeling with his hands any feedback motion through the steering that might give him information on how well he is guiding the tractor.

These three ways in which a person interacts with the product, as occupant of space, as sensor, and as controller, form the basis for the study of human factors, which plays a major role in the design of a device.

1.1 Controls in a Tractor Cab

The interior of the cab includes all the necessary amenities which help the farmer to perform desirable operations with maximum efficiency. A basic part of these amenities are the controls. A control is a device that allows the operator to 'communicate' with various objects in terms of transmitting information to them. The operator feels and senses the responses of the power, efficiency, and quality of the machine through manipulation of the controls. Controls in tractors have various operations (i.e., they adjust the tractor speed, the 3–point hitch, the differential lock and P.T.O. speed). The degree of operator fatigue and his safety during operation on difficult terrain are directly related to the effectiveness of the controls. When designing the control layout for the driver's workspace, the designer should minimize potential safety hazards through good understanding of the capabilities and the duties of the operator, the tasks to be performed, and the potential safety risks. As it is easily understood, their proper location in the work surface plays a significant role and must be of higher priority for the designers if an efficient work output is desired.

Controls can be found in various types such as hand and foot–levers, buttons, and switches. In old tractors the controls basically consisted of hand and foot–levers which, from an ergonomical perspective, were not very friendly to the driver due to their placement, moderate accuracy, length, weight, and the travel distance required in order to carry out a specific operation (Ely et al. 1956). Today, more sophisticated types of controls are being used to maximize the efficiency of the layout, while having the driver spending minimum effort. As a result, many new ideas regarding the placement, the type, and the functionality of controls have been developed. Modern tractor control panels are based mainly on levers, buttons, or knobs or on a combination of them depending on the manufacturer.

1.2 Definition of the Problem

Efficient operation of a machine depends upon the design of its control layout. Well–arranged controls, whose operational characteristics are based on design standards and on human factors considerations, allow the operator to easily assess and operate them maximizing the operation performance. The literature documents several factors that are of importance in the design of a control panel. These factors can be divided into two main categories.

The first category is related to control design including the type of control used, the physical dimensions of the control, and the frequency with which the control can be accessed. The second category considers human factors guidelines that are also very important due to fact that they express the interaction between the operator and the operational characteristics of a control including the labelling of the control, the distance of the control from the operator's seat, the suitability of the control, and the placement of the control.

Despite knowledge about each individual factor, it is not known how these factors should be combined to yield an overall ergonomic assessment of a specific control layout. Until today, the design for a given control layout is based exclusively on basic design guidelines and on the experience that the manufacturers may have from their previous products. Any new idea for ergonomic improvement of the layout (i.e., add a new type of control or change the existing type of control with another type) can be applied, if it is in accordance with the design standards, but the problem of the overall ergonomic assessment still remains. Specifically, the successful implementation of the different control types in the tractor workstation requires careful consideration of the activities performed and how the operator relates to the rest of the system (i.e., workstation). The effective design of the entire panel is one part of the equation. Its evaluation will require understanding the operator's capabilities and limitations in performing his or her duties.

According to the available literature there is no practical solution to overcome this obstacle because there is no way to mathematically assess the degree of functionality of the entire control layout before or after applying the specific new idea. Consequently, the following questions arise:

- How can we make an overall ergonomic assessment of a workstation based on mathematical results?
- Is it possible to evaluate an already existing control layout after making some changes to the control's arrangement and make sure that the new layout is more ergonomically acceptable for the operator?

Specifically, in the case of tractors, can we establish a way to compare old versus modern control layouts and determine the ergonomic improvements that may have occurred in the design of tractor workstations over the past 20 years in terms of controls functionality?

- How much, in mathematical terms, will be the difference between them?
- Will there be a significant difference or will the difference be negligible?

1.3 Importance of the Study

A new method capable of comparing, on a mathematical basis, different control arrangements, is of great interest. This is an important issue because the meaning of 'control access' is impossible to be determined practically, due to the fact that there are no existing standards in which one can rely on to make a comparison between control arrangements and the driver's operation convenience in the tractor environment.

To locate the controls in a cab and to promote safety and productivity, tractor manufacturers use a 'user–centred' design technique which usually begins by determining the operator's position and then arranging the instruments accordingly, based on design guidelines.

In past tractor cab design, just the opposite occurred. The instruments were located first and then the driver's seat was positioned. Thus, numerous complaints were reported from the operators regarding the inconvenient location of many instruments and generally the lack of ergonomic design inside the cab. However, the technique that is used today called 'user–centred design' cannot eliminate the problems of bad design as it is necessary to spend a long period of time using the controls in order to discover any design faults. For example, in a new cab model the possibility of making corrections to improve its ergonomic design may take years. The new product must first be used by a large number of individuals to let them know of any negative feedback regarding its design.

The establishment of a new assessment method can be very useful, especially for the design engineers, who would be able to test different drafts of control arrangements and discover which one is the most functional for the operator. Thus, the designers would be able to consider the ergonomic point of view at an early stage in the design process. Moreover, in case of improvement of an already existing control layout, the same method can be very helpful. As a result, the problem of increasing the speed of product development cycles while keeping costs to a minimum could be solved by the possibility of the early evaluation of drafts regarding their ergonomic design.

1.4 Rationale of the Model

In this study a new model is introduced and validated, referred to as the 'Index of Functionality', which is capable of comparing, on a mathematical basis, different control arrangements. The model is based on the inclusion of information that has been gleaned from the published literature regarding factors related to design of a control panel for agricultural tractors, with input from both professional ergonomists and experienced agricultural tractor operators. Using the new mathematical formula, it is possible to assess the degree to which the agricultural tractor's controls meet the requirements of the operator for easy and efficient operation. As a result, an ergonomic evaluation of various tractor workstations in mathematical terms can be conducted.

2. LITERATURE REVIEW

The 'Index of Functionality' takes into account two main categories related to the ergonomic design of a workstation. The first category is related to the design characteristics of controls that can affect their operation efficiency including the type of control used, the physical dimensions of the control, and the relative frequency with which the control can be accessed. The second category deals with human factors guidelines that are also very important due to fact that they express the interaction between the operator and the operational characteristics of a control including the labelling of the control, the optimum distance of the control from the operator's shoulder (functional reach), the suitability of the control, and the placement of the control.

A detailed review of books specializing in ergonomic design provides valuable background information for each factor mentioned. The purpose of this chapter is to present the information regarding the application of the human factors considerations in the design of control panels. However, the available literature does not provide any reliable method, which combines all the information, to mathematically describe a specific control arrangement.

2.1 Layout of Controls in Tractor Cab

Usually, agricultural tractor manufacturers separate the operation controls into three basic zones (Figure 2.1). The first zone (blue circle) includes the dashboard around the front steering column and both the warning and indicator lights. The second zone (green circle) includes the armrest for the continuously used controls of driving and hydraulic operations. Finally, the third zone (amber circle) includes a side control panel for other controls of less importance.

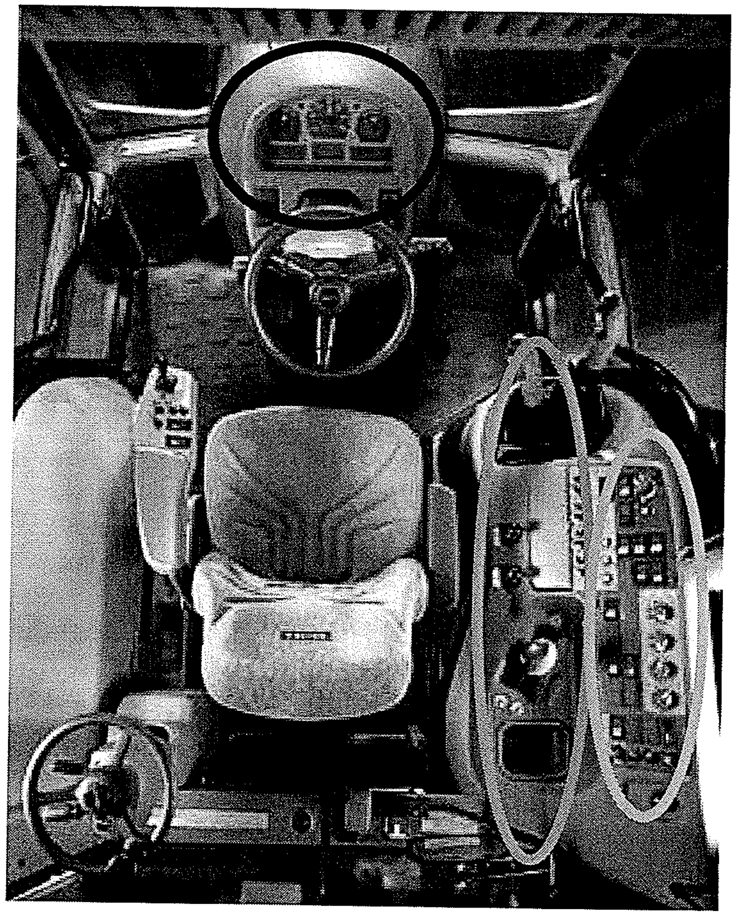

Figure 2.1 The three basic zones of controls in a tractor cab
(Source: Valtra tractors 2005)

2.1.1 Common Design Layouts in Tractor Cabs

A detailed examination of various tractor cabs shows that three different types of tractor control layouts exist. Figure 2.2 shows a control panel which is based mainly on a number of hand–levers. Specifically, there are nine hand–levers which the driver can use in order to make the necessary adjustments. This configuration is usually found in old tractors.

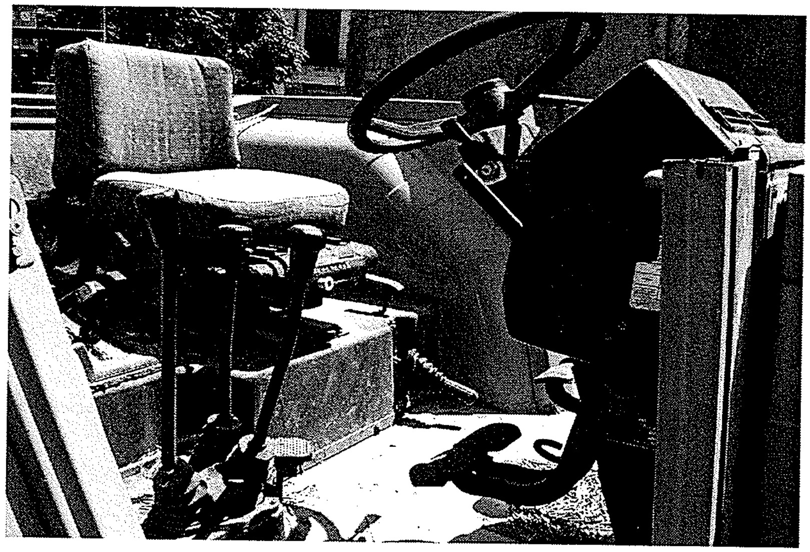

Figure 2.2 Control panel of a tractor based mainly on hand–levers

Figure 2.3 shows a control panel which is based on a combination of hand–levers, push buttons, rocker switches, joysticks, and knobs. A detailed examination of the specific layout shows that there are three hand–levers, three joysticks, and a number of buttons, rocker switches, and knobs that the driver can use in order to operate his tractor. This configuration is usually found in modern tractors.

Figure 2.3 Control panel of a tractor based on hand–levers, joysticks, buttons, rocker switches and knobs
(Source: Valtra tractors 2005)

The last example (Figure 2.4) shows a control panel which is based on two joysticks and a number of push buttons, knobs, and rocker switches. Each button has the appropriate label or scale indicating to the driver its specific operation. Although this panel represents the latest development in tractor cabs and gives the opportunity for the operator to make a number of adjustments while working in the farm, its ergonomic value in terms of functionality is questionable.

Figure 2.4 Control panel of a tractor based on joysticks, buttons, knobs and rocker switches
(Source: Valtra tractors 2005)

2.2 Human Factors Considerations

The compilation of human factors considerations provided in this chapter represents the beginning of a process. The understanding of human factors issues affecting tractor operators is still incomplete. Many of the issues surrounding the incorporation of different control types are still being debated (Sanders and McCormick 1993). Human factors guidance is helpful in addressing these issues. However, current literature does not specifically address the capabilities of the different control types and how they are related to each other (Rogers and Myers

1993). Additional research and continuing dialogue is needed to address these issues, as the tractor workstation continues to evolve.

The product of human factors considerations takes several forms including design principles, design guidelines, and design rules (Helander 1988; Dumas 1993). Design principles represent broad recommendations based upon research on how people behave towards the system. Principles, as Dumas indicates, are only goals. Guidelines are general recommendations that are tailored to the environment in which they will be used. Guidelines are more specific than principles. Smith and Mosier (1986) cite the following guideline: 'Ensure the computer acknowledges every control entry immediately; for every action by the user there should be some apparent reaction from the computer'. Human factors guidelines can aid in the design and evaluation of new or existing tractor workstations. While there is a rich body of human factors research, much of it was not written and organized for use by those developing or evaluating these systems. The available literature is located in diverse places that include journal articles, technical publications, textbooks, and conference proceedings. Human factors guidelines are available, but they are often general in nature and have not been focused to accommodate the specific requirements of the tractor environment.

Design rules are a series of design specifications for a particular system and are sufficiently detailed such that they do not require additional interpretation (Helander 1988). A design rule might specify the recommended dimensions or the recommended force range of various control types. Design rules are necessary because different designers can implement the same guideline in different ways. Design rules enable designers to maximize consistency in the application of design guidelines.

As effective as individual guidelines and design rules may be in supporting a 'user–centered' design of the cab; they may give an incomplete picture of how well the various controls are arranged. This can be explained by the fact that each control type is still part of a larger system. When all the components are put together, the system may be lacking from a human factors perspective. Interactions between various components may lead to unanticipated consequences. Until today, the most frequently used method for learning about these problems is through usability testing (Dumas 1993).

As mentioned in the previous chapter, 'user–centred' design, sets as a first priority, the position of the operator in order to locate the various instruments in a control layout. In fact, this concept is the starting point from which a further exploration of the interaction between the operator and the system can be conducted. An examination of four basic ergonomic factors, that are considered in this study, regarding the interaction between the operator (i.e., driver) and the system (i.e., workstation) will be presented.

The following sections will provide to the reader the necessary background information that has been gleaned from the published literature with reference to McFarland (1946), Chapanis et al. (1949), McFarland et al. (1953), Van Cott and Kinkade (1972), Gamst (1975), U.S. Army Material Command (1976), Seminara et al. (1977), NASA (1978), National Safety Council–Accident Facts (1978), Purcell (1980), Banks and Boone (1981), Moussa–Hamouda and Mourant (1981), Burgess (1986), Pheasant (1986), Smith and Mosier (1986), Chaffin (1987), Salvendy (1987), Grandjean (1988), Helander (1988), Miller and Swain (1988), Tullis (1988), Bailey (1989), Ivergard (1989), Laux (1991), Shneiderman (1992), Woodson (1992), Dumas (1993), Nielsen (1993), Rogers and Myers (1993), Sanders and McCormick (1993), Corlett and Clark (1995), NASA (1995), U.S. Department of Transportation (1996), ISO 3767–1 (1998), ASABE S304.7 (2000), ASABE S335.4 (2004) and Wikipedia (2005).

2.2.1 General Principles

The human factors guidelines presented in the next sections are representative of a small, but important set of human factors principles. These principles are listed below:

- 'A systems approach acknowledges that the operators, machines, processes, and environments do not operate in isolation, but as part of an integrated whole' (Sanders and McCormack 1993). One of the basic concepts to improve the overall accessibility of a workstation is to adapt a systems approach to the design and development process of the tractor cab. In designing or evaluating the individual controls in the tractor cab, we must recognize that they do not operate separately. Changing one part of the system may impact the other parts.

- A 'user–centered' design approach is used, which means designing the system around the operator. This approach not only recognizes the limits of the human operator to receive, process, and act on information; but also recognizes the environmental and physiological factors that limit performance such as temperature and humidity, noise and vibration, and anthropometric characteristics (Burgess 1986). A 'user–centered' design also puts the operator in charge. This means that the tractor operator initiates actions rather than simply responding to changes in the state of the system.

- One of the goals of incorporating human factors principles into the design of the tractor cab is to eliminate the likelihood of operator error. While this is a worthwhile goal, human error may never be completely eliminated. To address errors that do occur, the system should include features that minimize the impact of these errors. Designing error–tolerant systems involves a number of steps that include prompt detection and corrective action (Miller and Swain 1988; Salvendy 1987). It is important to give prompt feedback to tell the operator when an operation error or equipment failure occurs.

- An important part in tractor operation is the way that the necessary information is transmitted to the driver. Using redundancy in coding information to increase the likelihood that the operator receives the information; and giving feedback after the operator activates a control helps the operator to understand what the system is doing (Sanders and McCormack 1993).

2.2.2 Application of Anthropometric Data

The tractor cab provides the main work environment for the farmers. The immediate work requirements of the tasks executed in the cab have to be met. The basis for this is the determination of a number of general size considerations which include: cab width, restrictions for cab height, and crashworthiness standards. Within these limits, the designer is faced with the task of designing a space that enables the operator to perform his tasks as safely and effectively as possible (Purcell 1980).

In addition, apart from the size considerations mentioned, special weight must be given to the arrangement of the workspace inside the tractor cab. It is general practice to use the 95th and 5th percentile anthropometric values in workplace design.

Typically, the male 95th percentile dimensions are used to set clearances. On the other hand, the 5th percentile dimensions are used to set reach envelopes to ensure that a short functional arm can reach critical controls (e.g., the steering wheel). In deciding who to design for, the designer is faced with several different principles for applying anthropometric data (Sanders and McCormick 1993).

- *Designing for extreme individuals* is appropriate when a design feature should accommodate most of the population (i.e., the distance of controls from the operator). In practice, this often means specifying a minimum or maximum value of the characteristic in question that accommodates most, but not all of the population (i.e., the 95th percentile for males and the 5th percentile for females).
- *Designing for an adjustable range* is appropriate when features can be adjusted to the individuals who use them (i.e., seats).
- *Designing for the average individual* is appropriate in non–critical situations, where designing for an extreme is inappropriate and where adjustability is impractical (i.e., steering wheel).

In determining how the equipment will be adapted to fit the driver, the designer must specify where it will be located and how they will relate to each other. Anthropometric data provides essential information about the body's dimensions that the designer can use to achieve this objective. The current guidelines are based upon anthropometric data that is representative of the general population (Chaffin 1987; Grandjean 1988; Sanders and McCormick 1993; and NASA 1995).

In the case of tractors, Purcell (1980) suggests that dimensions for the 2.5 percentile to 97.5 percentile should be used to include 95 percent of the population. Specifically, a tractor designer, as Pheasant (1986) notes, should also consider that the current worldwide marketing of many given tractor models creates the need to take into account the use of ethnic anthropometric data in order to design a product which will cover the specific demands for each market.

The most important principles that the designer must follow in order to design an ergonomical work surface are presented below. Emphasis is given to the human factors considerations in relation to the placement of various components (i.e., controls) in the tractor cab. This task is very complicated and time consuming as the designer has to combine many issues simultaneously and make the necessary decisions. Often a rearrangement is required after tests showing that a control must be changed in position, redesigned, or not placed at all.

2.2.3 Principles of Controls Arrangement

Although there are no existing standards regarding specific control placement, some general principles have been developed based on several issues that need to be addressed in deciding where to position controls on the work surfaces. The designer needs to select a method by which controls will be distributed on the work surface. Knowledge of tasks to be performed, anthropometric data, and environmental factors will help determine where to locate controls. The following factors are commonly considered to determine their ideal position on the work surface (Sanders and McCormick 1993):

Frequency of use. Ideally, all controls would be placed in the optimum location for their purpose. This would depend on driver characteristics, such as his size, movement, vision, and hearing capabilities. Moreover, controls should be located in the optimum space, according to some criterion of use, such as convenience, accuracy, speed, or strength to be applied. Generally, agricultural tractor manufacturers consider controls in terms of the optimum, and the overall dimensions. Optimum dimension is defined as the most desirable space for the location of controls. As a result, highest priority controls should be placed within this region (e.g., the controls that the driver uses frequently). Overall dimensions define the acceptable, but not necessarily the most desirable dimensions or space. Therefore, desirable less important controls (e.g., controls used periodically during normal operations) would be placed within this region. The overall space will always be larger and will include the space defined by the optimum dimensions.

Sequence of use. If several controls are used in a specific sequence, that order must be reflected on the work surface. A characteristic example of this principle is presented in Figure 2.5. Three hand–levers are placed in a specific sequence which has a declining height. The longest hand–lever is the primarily used lever followed by the less long and the least long levers.

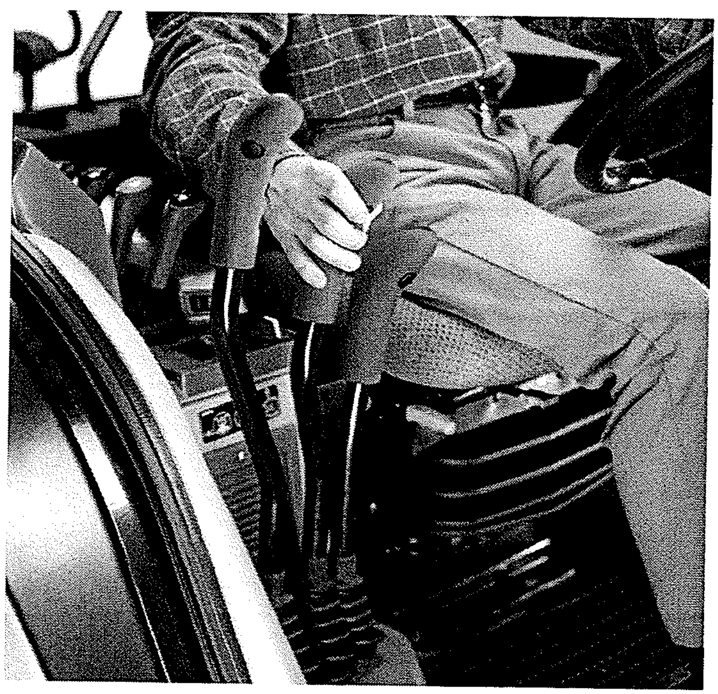

Figure 2.5 The sequence of use principle based on three hand–levers with declining height
(Source: Valtra tractors 2005)

Degree of importance–Location within operator reach. Where levers or buttons vary in importance, the most important of them are placed within the operator's functional reach grip, and the less important, are placed farther from his functional reach grip. Figure 2.6 illustrates this principle. The lever that the driver operates and the other longer lever beside it are placed near his hand in contrast to the other five levers that are placed farther, in a position which requires head movement. In this particular example, there is an assumption that the two levers located near the driver are the most important.

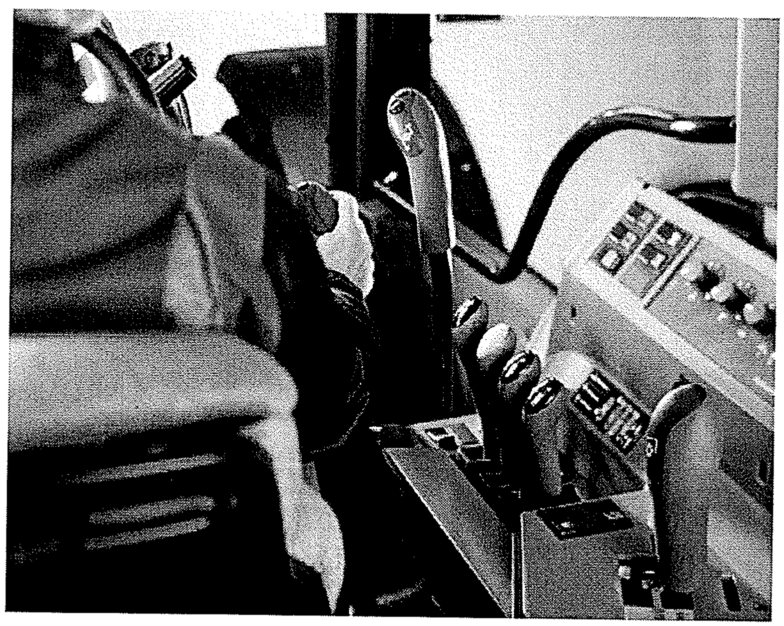

Figure 2.6 The degree of importance principle based on different hand–levers
(Source: Valtra tractors 2005)

Similarity of function–Label and color coding of controls. Instruments which perform the same function are grouped together. This grouping can be highlighted by the use of colour, labeling, or simply by placing groups of items that have the same shape and size in rows (Figure 2.7). A moderate number of coding categories can be used, and colours can often be picked that are meaningful - for example red for an emergency stop control. Labels are probably the most common method of identifying controls and should be considered as the minimum coding requirement for any control (Van Cott and Kinkade 1972).

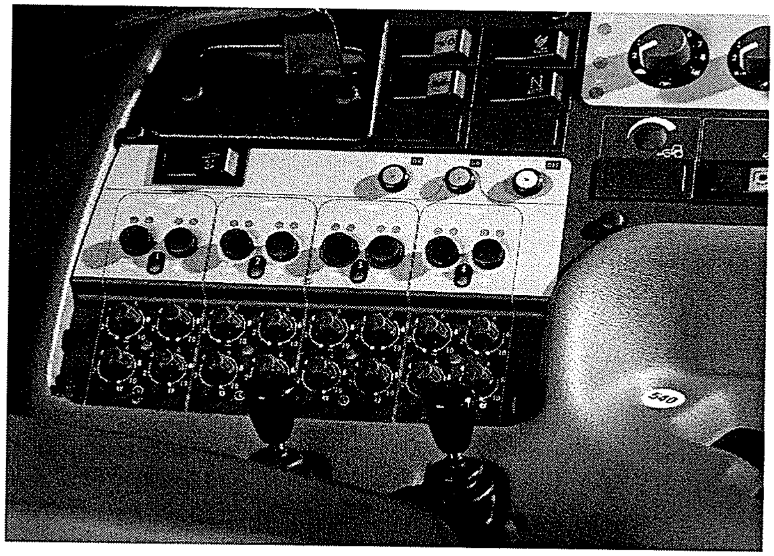

Figure 2.7 Controls grouped according to their functions
(Source: Valtra tractors 2005)

Mechanical design of controls. Controls should be made to operate smoothly, without looseness and with only a minimum range of movement to allow sufficiently accurate operation. The force required to operate each control must be dependent, not only on the mechanical requirement, but also on how rough the riding condition is for any particular type of work (Purcell 1980). Also, the suitability of controls is an important issue as their mode of action must be appropriate to their function. The use of controls that do not have the proper suitability to the type of the task required to be done can lead to a number of wrong operations which can influence the operator's safety (Sanders and McCormick 1993).

2.2.4 Workstation Design

The layout of the workstation should be designed to give the operator good exterior cab visibility, the ability to monitor all displays and controls, the ability to conveniently reach all controls, and adequate clearance to manoeuvre (Grandjean 1988; Ivergard 1989; Sanders and McCormick 1993; Woodson 1992). Consistency is an essential element in tractor workstations. Consistency in design and in control types facilitates learning and remembering how the system operates, reduces the likelihood of errors, and results in faster operation (Shneiderman 1992). Tractor control layout should be compatible with how operators organize information and act on their environment. As a result, designers and evaluators should take into account population stereotypes and user expectations in order to provide an efficient workstation. When there are many controls and displays to arrange in the workstation, consideration is given to the use of angled work surfaces (Sanders and McCormick 1993). Placing controls on an angled surface allows the placement of a greater number of controls within easy reach.

The compatibility between controls and displays is a very important factor which influences the proper operation of a workstation. Designing the controls and displays to be consistent with the operator's expectations will speed learning, reduce errors, and reduce response time (Pheasant 1986). Bailey (1989) states that the force, speed, accuracy, and range of body movements required to operate a control should never exceed the capability limits of the least capable user. In fact, these performance requirements should be considerably less than the abilities of the least capable user. In addition, the control surface should be designed to prevent the finger, hand, or foot from slipping.

2.3 Placement of Controls (Pc)

According to the literature, the placement of controls seems to be the most important ergonomic factor which ensures a safe and efficient operation. As Van Cott and Kinkade (1972) note, controls should be arranged in such a way to minimize the requirement for operators to change their position solely to operate a control. A further study by Woodson (1992) confirmed this suggestion. Specifically, he showed that all controls should be positioned so that, in manipulating them, operators do not appreciably move their nominal eye reference and possibly miss seeing important events occurring outside or on the principal internal display.

Many authors emphasized the contribution of control placement in safety of tractors (Purcell 1980; Grandjean 1988). This issue is one of the most serious challenges that designers must face as many accidents in the United States were caused due to the bad placement of controls (National Safety Council, Accident Facts 1978).

In 1980, Purcell developed a guide on the human factor in farm equipment design. In this guide, he suggested that all controls in the tractor cab which required accurate manipulation must be grouped on the right hand side of the operator, leaving his right hand side available for steering at all times. A review of any kind of tractor shows that until today, this statement is strictly followed by manufacturers. Although, this concept seems to be generally accepted in the agriculture industry, it is not in accordance with the information provided by Wikipedia (2005) where approximately 10–13% of the total population is left–handed.

Many years later, Sanders and McCormick (1993) stated that controls which have a similar function or purpose should be grouped together. They suggested several methods that can be used to reinforce the grouping such as location, shape, size, colour coding, and labelling. Special care should be taken when dimensional coding is used to ensure that all operators will be able to operate the controls and not activate another control inadvertently. This is especially important in cold northern climates when operators can be expected to wear bulky clothes and winter gloves. Typically, in these cases, hand controls should have as a minimum 50 mm clearance between the control and any other control or adjacent surface (Laux 1991).

Summarily, procedural efficacy in operator workplace design concerns the logical arrangement of task elements to enhance operator performance and minimize errors. Proper association between controls and displays along with logical grouping of controls is important in a compatible man–machine system. A number of standards and engineering practices are used to achieve proper location of operator controls and instruments. ASABE Standard S335.4 (2004) provides guidelines for the uniformity of location and direction of motion of operator controls to improve operator efficiency and convenience in tractors. The placement of tractor controls should conform to the mentioned ASABE published standard to simplify control learnability and minimize the need for control exploration prior to using the tractor for work by farm workers unfamiliar with a new tractor.

2.4 Suitability of Controls (Sc)

In selecting the type of control, it is important to make the actions required by the system match the intentions of the possible user (US Army Material Command 1976). A bad example that Sanders and McCormick (1993) refer to is to design the steering wheel of a car so that it rotates clockwise for a left turn–opposite to the intention of the driver and inconsistent with the effect on the system.

Early work by Van Cott and Kinkade (1972) showed that the direction of movement of controls should generally be related to the purpose or function of the control action rather than to the particular intervening mechanism used to accomplish the desired function. This concept is absolutely necessary for having a safe work environment while minimizing the operation errors. Table 2.1, developed by Corlett and Clark (1995), shows control recommendations using criteria of accuracy, speed of operation, force, range, number of discrete settings, and emergency action. Based on this table, the importance of having the proper control for a specific type of operation can easily be understood.

Generally, it is important for designers to make sure that the expected operators in a control layout can easily understand the relationship between the intention and the action and the relationship between the action and the effect on the system (Grandjean 1988). A product must be designed so that when a person interacts with it, there will be only one obviously correct thing to do; otherwise the risk of accident would be very high.

Table 2.1 The general suitability of controls for different types of operation

Control Type	*Accuracy*	*Speed*	*Force*	*Range*	*No. of discrete settings*	*Emergency action*
Push Button	–	H	–	–	2	H
Toggle Switch	–	H	–	–	2–3	H
Rocker Switch	–	H	–	–	2–3	H
Rotary Switch	H	H	–	–	3–24	M
Hand – Lever:						
Horizontal	L	H	L	L	–	M
Vertical (to/from body)	M	H	L	L	–	H
Vertical (across body)	M	M	M	–	–	M
Joystick (lever)	M	M	L	L	–	L
Knob	H	–	–	M	–	–
Pedal	M	M/H	L	–	–	H

General suitability: H = High; M = Medium; L = Low; – = Unsuitable or not applicable

(Source: Corlett and Clark 1995)

2.5 Functional Reach (Fr)

Functional reach represents the most important principle regarding the arrangement of components within a physical space: The *Importance Principle* (Sanders and McCormick 1993). This principle states that important components must be placed in convenient locations in which they can be reached without undue arm exertion. Specifically, this principle is derived from the 'functional reach grip' anthropometric dimension and implies that the operator should not work under stretching conditions (e.g., shoulder stretching). Pheasant (1986) defines the term 'functional reach grip' as the horizontal distance from the operator's shoulder to the tip of the thumb, measured with the subject's shoulders against the seat, the arm extended forward and the index finger touching the tip of the thumb. It must be noticed that one shoulder must not extend forward as far as possible whereas the other shoulder must be kept firmly pressed against the seat. These two conditions are satisfied in another anthropometric dimension which is defined by Pheasant (1986) as 'functional reach grip, extended'.

The difference between these two terms can be explained by the posture (seated or standing) of the operator during the work hours. For a seated operator, it is necessary for controls to be located within his 'functional reach grip' because any extended forward or extra movement of the shoulders further from their initial posture can lead to fatigue and increases the risk of pain and injury to the back and shoulders, especially during long work hours (Grandjean 1988). For a standing operator, due to the fact that there is more flexibility in his movements, it is desirable for controls to be located within his 'functional reach grip', but not necessary. According to Grandjean, in this case, the risk of injury is less, and as a result some of the instruments (e.g., those that are not frequently used) can be located outside of his 'functional reach grip'.

In considering how much space the driver can effectively use, two areas, normal and maximum, are commonly used (Sanders and McCormick 1993). The normal area represents the horizontal surface area that can be conveniently reached with the sweep of the forearm while the upper arm hangs in a natural position. The maximum area is the area that can be reached by extending the arm from the shoulder.

The reach requirements vary with several variables that include the type of control, kind of clothing worn, and whether the operator is restrained. The type of control will affect the reach requirement due to the part of the body that operates the control. Toggle and push button controls that are activated by finger tip will have a longer reach than a knob operated by a thumb or finger. Control levers that are operated with grasping actions of the entire hand, will have even shorter reach limitations. Van Cott and Kinkade (1972) recommend a maximum distance for controls operated with the whole hand of 686 mm (27 in) and 737 mm (29 in) for finger–operated controls.

Purcell (1980) combined a graphical layout and anthropometric data published by McFarland et al. (1953) and NASA (1978) in order to develop a graphic solution for optimum seating placement and location of controls (Figure 2.8). Figure 2.9 is a top view of Figure 2.8. A detailed review of the following figures shows that the maximum reach zone (finger grip) of a 5^{th} male percentile is defined at 750 mm (29.5 in) covering a 180° envelope in front of the operator from the 'Seat Reference Point' (SRPo).

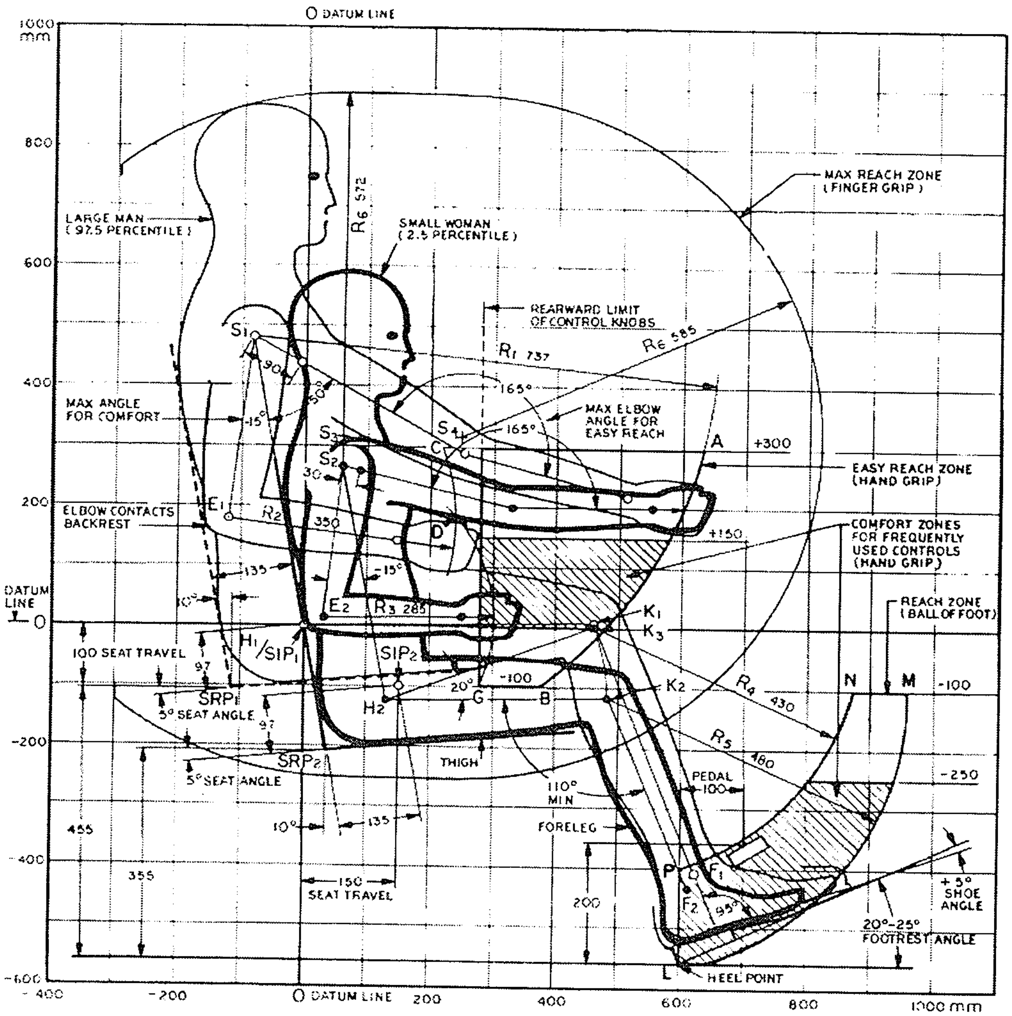

Figure 2.8 Graphic solution for finding optimum hand and foot control positions
(Source: Purcell 1980)

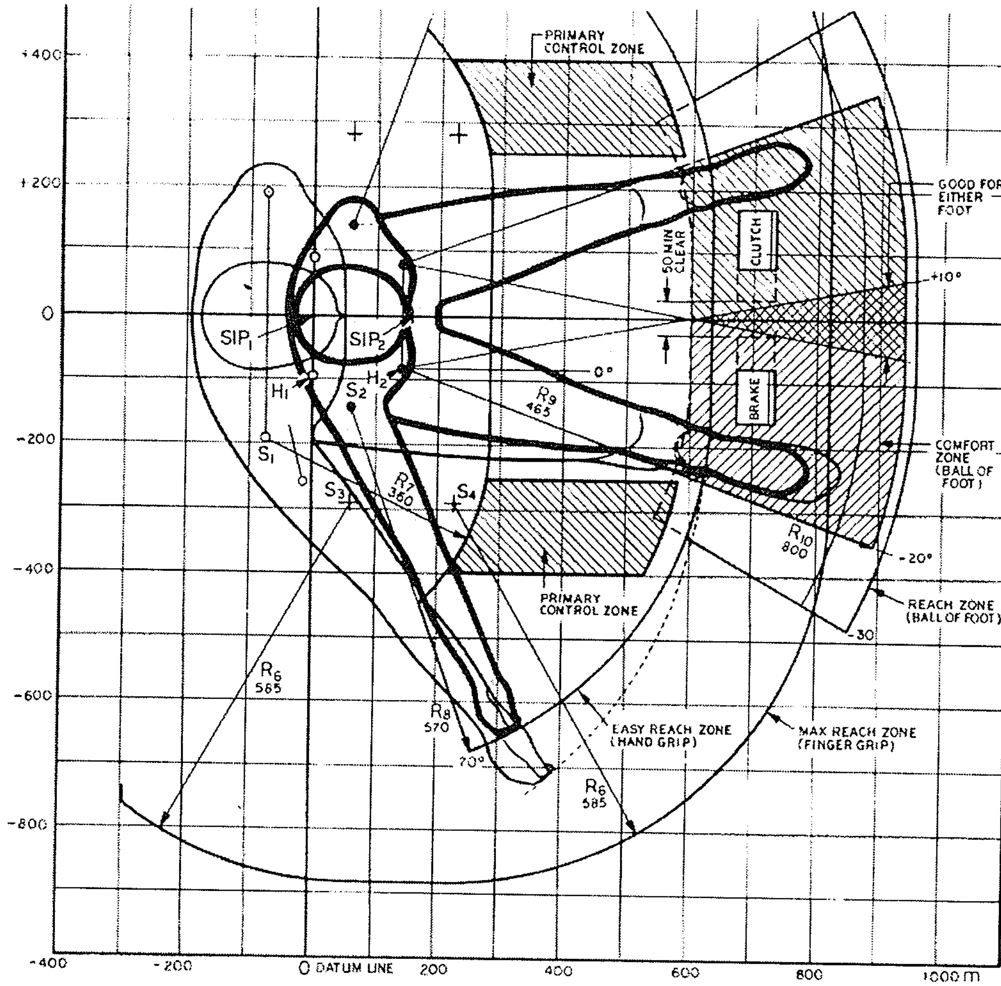

Figure 2.9 Optimum hand and foot control positions (top view of Fig. 2.8)
(Source: Purcell 1980)

2.6 Control Labelling (Lc)

Control coding is an issue of high importance for the operators working in any control layout. Studies conducted by Sanders and McCormick (1993) have showed that the identification of controls is essentially a coding problem. Thus, they categorized the primary coding methods based on shape, size, location, operational method, colour, and labelling. Table 2.2 presents the advantages and disadvantages of the different types of coding as published by the U.S. Department of Transportation

(1996). A detailed examination of the table below shows that the types of coding which have the less disadvantages are presented in the case of labelling and colour. This phenomenon can give a satisfactory explanation to the reason why tractor manufacturers mainly use labels and colours for control coding.

Table 2.2 Advantages and disadvantages of different types of coding

Advantages	**Location**	**Shape**	**Size**	**Mode of operation**	**Labelling**	**Colour**
Improves visual identification	X	X	X		X	X
Improves non visual Identification (tactual and kinesthetic)	X	X	X	X		
Helps standardization	X	X	X	X	X	X
Aids identification under low levels of illumination and coloured lighting	X	X	X	X	X	X
Requires little (if any) training					X	
Disadvantages						
May require extra space	X	X	X	X	X	
Affects manipulation of the control (ease of use)	X	X	X	X		
Limited number of available coding categories	X	X	X	X		X
May be less effective if operator wears gloves		X	X	X		
Controls must be viewed (e.g., must be within a visual areas & with adequate illumination present)					X	X

(Source: U.S. Department of Transportation 1996)

Making controls easy to identify decreases the number of times a wrong control is used and reduces the time required to find the correct control (Van Cott and Kinkade 1972). Although the correct identification of controls is not critical in some circumstances, there are some situations, however, in which their correct and rapid identification is of major consequence. For example, McFarland (1946) cites cases and statistics relating to aircraft accidents that had been attributed to errors in identifying control devices. Gamst (1975) reports that, in some railroad locomotives, engineers intending to turn off the signal lights grasp the wrong control and actually turn off the fuel pumps instead, thus killing all the diesel engines in the train. Moussa–Hamouda and Mourant (1981) interviewed 405 automobile drivers with cars equipped with fingertip reach controls attached to the steering column. Of the 405 drivers, 44 percent reported instances of inadvertent operation such as intending to operate the turn signal and instead turning on the windshield wipers.

One simple and effective way of coding controls is labelling. Labels are probably the most common method of identifying controls and should be considered as the minimum coding required for any control. Early work by Chapanis et al. (1949) showed that adequate space, visibility, and lighting are the prerequisites for using this method. Generally, a large number of controls can be coded with labels and, if properly chosen, do not require much learning to comprehend. Extensive use of labels as the only means of coding controls is not desirable according to Sanders and McCormick (1993) and Van Cott and Kinkade (1972). A disadvantage that they mention is that labels take time to read and thus should not be the only coding method where speed of operation is important. Nevertheless, Seminara et al. (1977) reported that in most nuclear power plant control rooms, there are literally walls of identical controls, distinguished only by labels.

Years later, a further study from Corlett and Clark (1995) defined the proper location of labels. They demonstrated that labels not only should be placed above the control, so that the hand will not cover them when the operator is reaching for the control, but also should be visible to the operator before reaching for the control.

Another usual way of coding controls that literature mentions is the use of standardized icons or symbols. Purcell (1980) reports the significance of control coding using symbols. Symbols and icons in particular, can aid recognition and comprehension by representing objects in ways that mimic their appearance (Tullis 1988). However, to be effective, the designer must be able to create symbols and icons that are meaningful and familiar to the user. Particularly for tractors, the American Society of Agricultural Engineers has established a guide which presents different standardized graphical symbols that can be used on operator controls (ASABE S304.7 2000) and are in accordance with the latest relevant ISO standards (ISO 3767–1 1998). In fact, among the farmers, the issue of control coding is of less importance. Many tractor operators agree that the factor of control labelling during long working hours, has less impact on their performance. They claim that operators access individual controls by memorizing their location and reach distance, rather than by labelling. However, the existence of some type of labelling or training manual for operators is desirable to initially familiarize themselves in the case of a new cab control environment.

Of course, in control coding, there are some independent factors that influence its effectiveness such as the character height presented in labels. Van Cott and Kinkade (1972) concluded that readability is affected by its size. Specifically, they noticed that the optimal height of characters will vary with distance of the viewer from the label. Table 2.3 shows recommended heights for different luminance conditions based on the study by Sanders and McCormick (1993).

Table 2.3 Recommended heights of alphanumeric characters for critical and noncritical use under low and high illumination

	Height of numerals and letters*	
	Low Luminance (Below 3.5 cd/m² (1 ft–L)	High Luminance (Above 3.5 cd/m² (1 ft–L)
Critical use, position variable	5 – 8 mm (0.2 – 0.31 in)	3 – 5 mm (0.12 – 0.2 in)
Critical use, position fixed	4 – 8 mm (0.16 – 0.31 in)	2.5 – 5 mm (0.1 – 0.2 in)
Noncritical use	2.5 – 5 mm (0.1 – 0.2 in)	2.5 – 5 mm (0.1 – 0.2 in)

*Values assume a 710 mm (28 in) viewing distance. For other distances, multiply the above values by D/710 mm (D/28 in).

(Source: Sanders and McCormick 1993)

Colour can be useful for identifying controls as well. Purcell (1980) notes that in a tractor cab a maximum number of four colours can be used which must be meaningful (e.g., red for an emergency stop control). Table 2.4 presents the standard colour meaning which is used in general colour coding of controls as defined by U.S. Department of Transportation (1996). One disadvantage of colour coding is that the operator must look at the control to identify it (Sanders and McCormick 1993; Corlett and Clark 1995). This fact can be confusing in tractor operation where the operator must react immediately whenever a dangerous situation appears. On the other hand, Purcell (1980) recommends the use of colour coding in tractors. He supports the idea that colour is particularly useful in giving visual separation between groups of controls. This seems to be a logical statement, especially in cases where the operator faces an area with two or three controls which are related to speed and three or four hydraulic function controls. In this situation, according to Purcell, by making the speed group red and the hydraulic group black, the area appears less cluttered and confusing than if they were all one colour.

Table 2.4 Standard colour meaning used in colour coding of controls

Colour	Meaning	Explanation	Typical Applications
Red	Danger or Alarm	Warning of potential danger or a situation that requires immediate action.	Failure of pressure in a lubricating system. Temperature outside specified limits. Activation of a safety system.
Amber/ Yellow	Caution	Change or impending change of conditions.	Pressure or temperature different from normal level.
Green	Safety	Indication of a safe situation or authorized to proceed.	Cooling liquid circulating. Automatic boiler control in operator. Machine ready to be started.
Blue	Instruction/ Information	Any meaning not covered by the above colours.	Motor ready to start. Pump in standby re–circulation.
White	No specific meaning assigned (Neutral)	Any meaning. May be used where doubt exists about the application of red, green or yellow/amber. Often used for confirmation.	Synchronizing lamps (for A/C bus alignment).

(Source: U.S. Department of Transportation 1996)

2.7 Theoretical Methods for Evaluating Workstations

All the information described above must be followed to design an effective and friendly workstation for the operator. Currently, the available evaluation methods for workstations are separated into two categories. The first category is the usability testing which is defined as the technique used for ensuring that the intended users of a system can carry out the intended tasks efficiently, effectively, and satisfactorily (Dumas 1993). According to Nielsen (1993), the main goal of usability testing is to assess the overall quality of the system by discovering which aspects of the system are designed in a good or bad manner.

However, usability testing is not a substitute for a human–centred design process, which is the main design method for the workstations used in tractors. The fact that this technique evaluates only the individual instruments, and does not consider that they are part of a whole system, can explain the reason why it can not be used as an evaluating method in tractor workstations.

On the other hand, the second category is based on several general guidelines which are presented below (Chaffin 1987, Grandjean 1988, Sanders and McCormick 1993):

- The hands should not have to reach frequently or be held for sustained periods above the shoulder.
- The use of padded forearm is required as it supports to relieve pressure at the shoulder and elbow.
- The design of the workstation should be adjustable to the operator so that his or her elbows remain flexed (bent). The position in which the operator's elbows are at a 90–degree angle requires less effort than when the elbow is in an extended position. This goal may be achieved by designing the work surface to be at the same height as the elbow height.
- An adjustable work–surface height must be provided to fit individual physical dimensions and preferences. Grandjean (1988) recommends an adjustable range of 60–70 cm. The need for a low work surface may conflict with clearance levels needed to provide enough knee space.

Although these guidelines can be characterized as useful; they do not provide any specific information regarding the physical dimensions and the operational characteristics of the various instruments and the environment where the operation is conducted. To rely only on these guidelines would result in an incomplete assessment.

In conclusion, the two methods mentioned are based only in a theoretical framework and, therefore, they do not provide a practical result such as a mathematical value or an indication which can describe the overall ergonomic acceptability of a control layout.

2.8 Existing Models for Evaluating Workstations

Until today, there is only one known attempt to arrange control devices in a control layout proposed by Banks and Boone (1981). They developed a mathematical formula called 'Control Accessibility Index'. Among the several variables mentioned in the previous sections of this chapter that can affect the relative accessibility of controls, Banks and Boone developed their quantitative index of accessibility based on (1) the frequency of use, (2) relative position of controls with respect to the operator, and (3) the operator's reach envelope. The index $I\alpha$ was derived in part from ratings made by subjects who used mock–ups of three control panels for experimental purposes. The results reflected the feasibility of deriving a quantitative index of accessibility for use in locating controls within an operator's work–space envelope or in its general vicinity.

2.9 Objectives of the Study

The objectives of this study were:

1. To develop a numerical index, referred to as an 'Index of Functionality', capable of comparing, on a mathematical basis, different control arrangements in tractors.
2. To apply the 'Index of Functionality' in old and modern tractors in order to determine its capability to recognize improvements that have occurred in the

ergonomic design of tractor cabs over the past 20 years in terms of control functionality.

In the next chapters, a comprehensive analysis of the development method that has been followed will be presented including a description of the factors that are included in the mathematical formula. This is essential for any individual that is interested in understanding not only the rationale of the model development but also the way that it can be applied to a tractor workstation. It is expected that the results from this study will establish a new 'era' for the people in the design industry as these results can be used as a starting point for changing their way of thinking regarding the process that is followed to design a control layout of an agricultural vehicle.

3. METHODOLOGY FOR MODEL DEVELOPMENT

In this chapter, the process that was followed to generate the necessary information for the development of the 'Index of Functionality' will be described. Basically, the model development was based on three main study areas: (1) the design standards for various types of controls, (2) the frequency with which categories of controls will be accessed during operation of a tractor, and (3) the human factors considerations that are of high importance in the tractor environment.

3.1 Design Standards for Various Types of Controls

The familiarity of the design standards for the various types of controls that are presented in tractors, was the first concern for the model development. Initially, the knowledge of the various control types that are found in modern tractors was crucial. As a result, a critical review of ten different modern tractor cabs was conducted during a local agricultural machinery exhibition event. Later, a decision was made regarding the number of control types that must be included in the model based on the reviewed results. The following control types were chosen because they represent the majority of controls that are used in modern tractors:

- Rotary Switches (Sr),
- Toggle Switches (St),
- Rocker Switches (S),
- Knobs (Kb),
- Push Buttons (Bp),
- Hand–Levers (L),
- Steering Wheel (Sw); and
- Multifunction Hand Controls (Mc).

Afterwards, a detailed study of several design textbooks was completed to identify the relevant published knowledge for each type of hand control.

3.2 Frequency of Use for Categories of Controls

The second concern for the model development was the determination of the frequency with which the various controls will be accessed during operation of a tractor. Controls were categorized into five groups according to their general function based on the opinion of the researchers and ten experienced agricultural tractor operators:

- Steering Wheel,
- Controls related to the functioning of the implement (e.g., 3–Point hitch, P.T.O. speed),
- Controls related to the motion of the tractor (e.g., Gearshift, Hand brake),
- Controls related to the internal environment (e.g., Air conditioning, Cigarette lighter); and
- Controls related to the external environment (e.g., Headlights, Turn signal).

For the purpose of this classification, tractor operators were asked verbally to confirm the suggested groups. The operators were located randomly among local farmers close to Patras, Greece. After confirming the mentioned groups, their ranking needed to be addressed and therefore, a survey was conducted. A questionnaire (appendix C) was distributed to ten farmers, asking each farmer to rank the five categories of controls according to their frequency of use during a tillage operation.

The survey took place in Greece during the summer of 2005. Subjects were recruited randomly among local farmers close to Patras, Greece based on their willingness to participate. A number of visits were conducted to farms in order to locate the required number of farmers. The duration of each personal interview was approximately 15 min.

3.3 Human Factors Considerations

The third concern for the model development was related to the human factors considerations. According to the published literature, the following four factors were chosen as critical due to the fact that they influence the performance in a tractor control layout:

- placement of controls,
- functional reach,
- suitability of controls; and
- labelling of controls.

The significance of the four mentioned factors was confirmed from 5 professional ergonomists (Chapter 4.3.5). The *placement of controls* is the basic principle which allows controls to be located within convenient reach. Also, the proper placement provides optimum visibility at all times by the driver/operator. Moreover, the appropriate placement is related with the frequency of controls. Frequently operated controls should be located in the most convenient location. Less frequently operated controls and controls with catastrophic consequences if erroneously activated, should be placed in less convenient locations, with increased separation from other controls.

The importance of the *functional reach* from a usability perspective can be summarized in the following three reasons. First, farmers spend long hours in a seated position which can lead to fatigue. Thus, it is essential for the driver/operator to maintain a comfortable seating position in the cab during long durations of operation.

Second, farmers have a high incidence of back or spinal conditions from injury or prolonged stress. Third, some controls are often accessed when twisting backward, which limits forward or sideways reach. As a result, with a less than optimal functional reach, the operator would have to assume less comfortable positions which could lead to fatigue or negative physical symptoms.

The *suitability of controls* is a very important consideration because if the mode of action of controls is not appropriate for functions, the operation will be prone to error. In addition, inappropriate control actions can increase operator fatigue/physical problems.

The *labelling of controls* is absolutely critical for control recognition. Without effective labeling, a control will be very confusing to the driver/operator and may result in improper use.

In order to emphasize the four mentioned factors significance in the tractor's environment, it was decided to give each of them the appropriate weight according to their relative importance. For this reason, five human factors experts participated in a survey by completing a questionnaire (appendix C); they were asked to distribute 100 points among the four factors considering their relative importance and to justify their decisions.

The survey was conducted electronically during the summer of 2005. Subjects were recruited by reviewing their e–mail addresses from the directory of Human Factors and Ergonomics Society (2005), based on their interest/research area. A contact letter including the questionnaire and general information about the survey procedure was sent through e–mail to eighty-two experts. Their interest/research area was related to the driver/operator performance in agricultural machineries and the human factors considerations in driver/operator environment. Five experts sent an immediate response and completed the survey successfully.

4. INDEX OF FUNCTIONALITY

The numerical index developed is called the 'Index of Functionality' (*IF*). The general equation is presented below (Eq. 4.1). Its possible values range between 0 and 1, with 1 being defined as the optimum value in terms of the functionality of an entire control panel.

$$IF = \frac{\dfrac{[(Fc1\cdot c1)+\ldots+(Fci\cdot ci)]+(Ea)\cdot[(WPc\cdot Pc)+(WSc\cdot Sc)+(WFr\cdot Fr)+(WLc\cdot Lc)]+Sw+Mc}{n}}{\Sigma F+(WPc+WSc+WFr+WLc)+2} \qquad \text{(Eq. 4.1)}$$

where:

Fc1,…, Fci=	relative frequency of use of different control types,
c1,…, ci =	ergonomic score of different control types,
Pc =	placement of controls,
Sc =	suitability of controls,
Fr =	functional reach,
Lc =	labelling of controls,
Ea =	ergonomic factors average,
WPc =	weight factor for the placement of controls,
WSc =	weight factor for the suitability of controls,
WFr =	weight factor for the functional reach,
WLc =	weight factor for the labelling of controls,
Sw =	steering wheel,
Mc =	presence of multifunction hand control; and
n =	total number of control types (excluding Sw and Mc).

In this chapter the information collected from the three main study areas will be presented. In the first section, all the detailed information that has been found on control types will be given. In the second section, the survey results regarding the determination of the frequency of use for the five categories of controls provided by farmers will be illustrated. Also, the procedure that has been selected to determine the relative frequency of use for the different control types will be described. In the third section, the survey results derived from human factors experts, regarding the weight determination of the four ergonomic factors according to their relative importance will be illustrated. At the end, the complete mathematical formula including all its coefficients will be provided.

4.1 Incorporation of the Various Control Types in the Model

When specifying a control, one must first consider the intended function of the control. Certain types of controls are best suited for certain applications. One simple way to classify controls according to Sanders and McCormick (1993) is based on the type of information they can most effectively transmit (discrete versus continuous) and the force normally required to manipulate them (large versus small). The amount of force required to manipulate a control is a function of the device being controlled, the mechanism of control, and the design of the control itself. Electric and hydraulic systems typically require small forces to actuate controls, whereas direct mechanical linkage systems may require large forces (Grandjean 1988). Generally, there are four basic kinds of functions. Bailey (1989) defines these as:

- Activation. A binary two–position control, usually either on or off. A cab light switch is an example.
- Discrete Setting. A control requiring three or more discrete settings. The tractor P.T.O. is an example.

- ➢ Quantitative settings. A control requiring continuous setting (i.e., infinitely variable through the range). The tractor brake control is an example.
- ➢ Continuous control. A control requiring constant adjustment. A tractor's steering wheel is an example.

Studies conducted by Purcell (1980) have shown that in modern tractors, controls can be found in various types such as: hand and foot levers; push buttons; switches; knobs; and multifunction hand controls which combine two or more types of controls.

It is not always possible to point to a single definite empirical study from which specific design specifications may be derived. The experience shows that commonly they are repeated from one source to the next with minor modifications. The recommendations which follow have been compiled with reference to Orlansky (1949), Hunt (1953), Dupuis et al. (1955), Dupuis (1957), Van Cott and Kinkade (1972), Purcell (1980), Wierwille (1984), Pheasant (1986), Grandjean (1988), Bailey (1989), Konz (1990), Howe et al. (1992), Sanders and McCormick (1993), Weimer (1993), Clark and Corlett (1995), NASA (1995) and US Department of Defense (1999).

No fixed procedure has been adopted in the attempt to establish a consensus view but, in general, the optimum values are within the limits quoted by most of the above authors, whereas the maximum and minimum values may be more contentious.

At the end of each of the following sections, a summary with the most acceptable recommended dimensions derived from the tables will be provided. In most cases, the recommended values from the authors, for each control type, do not present significant differences. However, the most recent publications were given special consideration. The rationale behind this idea is the fact that the current design standards better depict the latest design developments of controls. As a result, an effort was given to include all the recent values, giving special consideration to the optimum values proposed.

4.1.1 Rotary Switches

A type of control that is more commonly found in old tractors rather than in modern tractors is the rotary switch. Pheasant (1986) notes that this type of control is the preferred control for 2 to 24 settings. Rotary switches can have either a moving pointer and fixed scale or a moving scale and a fixed index, but a moving pointer with a fixed scale is preferred for most tasks (Van Cott and Kinkade 1972). Using tables generated by US Department of Defense (1999), I concluded that the most important design dimensions that can affect the operation efficiency of a rotary switch are its length, width, height, and its separation. Pheasant (1986) suggests an optimum length of 25–30 mm (1–1.2 in), height of 15–25 mm (0.6–1 in), and separation of 50 mm (2 in). As can be seen from Table 4.1, most authors recommended the same minimum length, height, and separation values; in the case of width there is a maximum value of 25 mm (1 in). By reviewing the following table, it can be summarized that there are no significant differences between the various recommended dimensions. As a result, acceptable dimensions for rotary switches are:

- Length: 25–76 mm (1–4 in)
- Width: $\leq$ 25 mm (1 in)
- Height: 12–75 mm (0.5–3 in)
- Separation: $\geq$ 25 mm (1 in)

Table 4.1 Various recommended Rotary Switch sizes which facilitate optimal control for an operator (*Optimum values)

Author	Year of Publication	Length mm (in)	Width mm (in)	Height mm (in)	Separation mm (in)
Corlett & Clark	1995	12–70 (0.5–2.8)	≤ 25 (1)	12–70 (0.5–2.8)	25–50 (1–2)
Van Cott & Kinkade	1972	25–76 (1–3)	≤ 25 (1)	12–76 (0.5–3)	OPT* 50 (2)
Grandjean	1988	≥ 25 (1)	≤ 25 (1)	12–70 (0.5–2.8)	N/A
Sanders & McCormick	1993	25–76 (1–3)	12–25 (0.5–1)	≥ 12 (0.5)	N/A
NASA–STD–3000	1995	N/A	N/A	N/A	OPT 40 (1.6)
MIL–STD–1472F	1999	25–100 (1–4)	≤ 25 (1)	16–75 (0.6–3)	OPT 50 (2)
Pheasant	1986	OPT 25–30 (1–1.2)	≤ 25 (1)	OPT 15–25 (0.6–1)	OPT 50 (2)
Weimer	1993	25–100 (1–4)	13–25 (0.5–1)	12–75 (0.5–3)	N/A
Konz	1990	N/A	N/A	N/A	OPT 25 (1)

4.1.2 Toggle Switches

An often-used control in both old and modern tractors is the toggle switch. Grandjean (1988) demonstrates that the toggle switch is the preferred control for on/off or other two–state selection. He also states that it may be used in three positions (e.g., on/standby/off), but the rotary switch is preferable in such cases. Similar findings have been presented by Pheasant (1986) and Weimer (1993). A further study from NASA (1995) regarding the operation efficiency of toggle switches showed that there are two important dimensions: the arm length and separation. NASA (1995) suggested an arm length between 13–50 mm (0.5–2 in) and optimum horizontal and vertical separation of 50 mm (2 in).

Table 4.2 presents various recommended toggle switch sizes from selected authors. A careful examination shows that almost all the authors give the same recommendations for both dimensions. This means that the toggle switch is a highly standardized control. Consequently, acceptable dimensions for toggle switches are:

- Arm Length: 12–50 mm (0.5–2 in)
- Separation: ≥ 50 mm (2 in)

Table 4.2 Various recommended Toggle Switch sizes which facilitate optimal control for an operator

Author	Year of Publication	Arm Length mm (in)	Horizontal Separation mm (in)	Vertical Separation mm (in)
Corlett & Clark	1995	13–50 (0.5–2)	≥ 12 (0.5)	OPT 75 (3)
Van Cott & Kinkade	1972	13–50 (0.5–2)	OPT* 25 (1)	OPT 50 (2)
Grandjean	1988	12–50 (0.5–2)	OPT 50 (2)	OPT 50 (2)
Sanders & McCormick	1993	12–50 (0.5–2)	OPT 50 (2)	≥ 50 (2)
NASA–STD–3000	1995	13–50 (0.5–2)	OPT 50 (2)	OPT 50 (2)
MIL–STD–1472F	1999	13–50 (0.5–2)	OPT 50 (2)	OPT 50 (2)
Pheasant	1986	15–50 (0.6–2)	OPT 50 (2)	OPT 50 (2)
Weimer	1993	12–50 (0.5–2)	OPT 50 (2)	OPT 50 (2)
Konz	1990	N/A	OPT 19 (0.7)	N/A

*Optimum values

4.1.3 Rocker Switches

This category of control can also be found in both old and modern tractors with the same frequency as toggle switches. US Department of Defense (1999) conducted laboratory studies regarding the usefulness of rocker switches. They found that rocker switches may be used in lieu of toggle switches for functions requiring two discrete positions. They also may be used for applications where toggle switch handle protrusions might snag the operator's sleeve or where there is insufficient panel space for separate labelling of switch positions. In addition they established the basic dimensions for a rocker switch (width, length, and the separation between centres). Their recommendations for the previously mentioned dimensions are: minimum width of 6 mm (0.25 in), minimum length 12 mm (0.5 in), and minimum separation of 19 mm (0.75 in).

Although it is difficult to find relevant information on design requirements for this specific type of control, the available published literature is in accordance with the dimensions that NASA (1995) provides. Design recommendations concerning the width, length and separation for rocker switches are given in Table 4.3. As it can be summarized from the table below, the majority of authors agree with the following dimensions:

- Width: ≥ 6 mm (0.25 in)
- Length: ≥ 12 mm (0.5 in)
- Separation: ≥ 19 mm (0.75 in)

Table 4.3 Various recommended Rocker Switch sizes which facilitate optimal control for an operator

Author	Year of Publication	Width mm (in)	Length mm (in)	Separation mm (in)
Corlett & Clark	1995	OPT* 25 (1)	OPT 15 (0.6)	N/A
Van Cott & Kinkade	1972	N/A	N/A	N/A
Grandjean	1988	N/A	N/A	N/A
Sanders & McCormick	1993	N/A	N/A	N/A
NASA–STD–3000	1995	≥ 6 (0.25)	≥ 12 (0.5)	≥ 19 (0.75)
MIL–STD–1472F	1999	≥ 6 (0.25)	≥ 12 (0.5)	≥ 19 (0.75)
Pheasant	1986	OPT 12–15 (0.5–0.6)	OPT 25–30 (1–1.2)	OPT 50 (2)
Weimer	1993	≥ 6 (0.25)	≥ 13 (0.5)	N/A
Konz	1990	N/A	N/A	OPT 25 (1)

*Optimum values

4.1.4 Knobs

Many tractor manufacturers, especially in modern tractors, provide their cabs with knobs. Grandjean (1988) notes that knobs should be used when low activation forces or precise adjustments of a continuous variable are required. This statement can explain the reason why, in modern tractors, knobs are more popular compared to other types of controls. In tractors there are a variety of operations that require adjustments on a continuous scale for gaining accuracy (Purcell 1980). Generally, for most tasks, a moving knob with fixed scale is preferred over a moving scale with fixed index according to studies conducted by the US Department of Defense (1999). A further study by Van Cott and Kinkade (1972) showed that the dimensions of knobs shall be within the limits specified in Table 4.4. Within these ranges, knob size is relatively unimportant, and it can be easily grasped and manipulated.

When panel space is extremely limited, knobs should approximate the minimum values and should have resistance as low as possible without permitting the setting to be changed by vibration or merely touching the control. Height, diameter, and separation between adjacent edges of knobs shall conform to Table 4.4. A careful review on the various design recommendations and especially on the optimum values confirms the fact that the majority of the authors provide the same dimensions for knobs. Like the toggle switch, the knob is also a highly standardized control with unquestionable value due to its simple mode of operation. Therefore, its recommended acceptable dimensions can be summarized as:

- Height: 12–25 mm (0.5–1 in)
- Diameter: 12–100 mm (0.5–4 in)
- Separation: ≥ 50 mm (2 in)

Table 4.4 Various recommended Knob sizes which facilitate optimal control for an operator

Author	Year of Publication	Height mm (in)	Diameter mm (in)	Separation mm (in)
Corlett & Clark	1995	12–70 (0.5–2.8)	25–100 (1–4)	25–50 (1–2)
Van Cott & Kinkade	1972	12–25 (0.5–1)	OPT 50 (2)	OPT* 50 (2)
Grandjean	1988	15–25 (0.6–1)	35–75 (1.8–3)	OPT 50 (2)
Sanders & McCormick	1993	12–25 (0.5–1)	OPT 50 (2)	OPT 50 (2)
NASA–STD–3000	1995	N/A	N/A	N/A
MIL–STD–1472F	1999	12–25 (0.5–1)	10–100 (0.4–4)	OPT 50 (2)
Pheasant	1986	15–25 (0.6–1)	OPT 15–30 (0.6–1.2)	OPT 50 (2)
Weimer	1993	12–25 (0.5–1)	10–100 (0.4–4)	OPT 50 (2)
Konz	1990	N/A	N/A	OPT 25 (1)

*Optimum values

4.1.5 Push Buttons

One of the most frequently–used type of controls for both old and modern tractors is the push button. US Department of Defense (1999) conducted experiments on the operation of push buttons. They concluded that this type of control should be used when a control or an array of controls is needed for momentary contact or for actuating a locking circuit, particularly in high–frequency–of–use situations. In addition, they showed that push buttons should not be used for discrete control where the function's status is determined exclusively by the position of the switch (e.g., an on–off push button that is pressed in and retained to turn a circuit on and pressed again to release the push button and turn the circuit off).

Their results agreed with previous findings presented by Van Cott and Kinkade (1972) and Pheasant (1986). Van Cott and Kinkade (1972) conducted a further study to show the benefits of using push buttons. They mentioned that in most cases push buttons require only a small amount of panel space. In addition, results showed that they can be operated quickly and simultaneously with other push buttons in an array and that they can be identified easily by their position within an array or by their associated display signal. The main disadvantage as Hunt and Orlansky (1953 and 1949, cited by Van Cott and Kinkade 1972) note is that push button control setting is not easily identified, visually or tactually. The solution concerning this obstacle was given by Van Cott and Kinkade (1972). They suggested the use of a concave surface to deal with tactual problems and the use of a positive indication of control activation regarding visual problems.

Later, NASA (1995) developed a dimension guide for push buttons. Their design recommendations regarding the diameter and separation between adjacent edges are given in Table 4.5. It is noticeable that all the author's recommendations present a significant similarity. The most common recommendations among the authors that can be used as a guide in its design are:

- Diameter: 12– 25 mm (0.5–1 in)
- Separation: ≥ 50 mm (2 in)

Table 4.5 Various recommended Push Button sizes which facilitate optimal control for an operator

Author	Year of Publication	Diameter mm (in)	Separation mm (in)
Corlett & Clark	1995	12–25 (0.5–1)	15–22 (0.6–0.9)
Van Cott & Kinkade	1972	≥ 12 (0.5)	12–50 (0.5–2)
Grandjean	1988	12–15 (0.5–0.6)	OPT* 50 (2)
Sanders & McCormick	1993	≥ 12 (0.5)	OPT 50 (2)
NASA–STD–3000	1995	≤ 40 (1.5)	N/A
MIL–STD–1472F	1999	10–25 (0.4–1)	OPT 50 (2)
Pheasant	1986	12–15 (0.5–0.6)	OPT 50 (2)
Weimer	1993	10–19 (0.4–0.75)	OPT 50 (2)
Konz	1990	N/A	OPT 50 (2)

*Optimum values

4.1.6 Hand–Levers

The hand–lever is a very important control in the agricultural industry and for many years was the primary control that was used in tractors. Although its use today has been partly replaced by other types of controls, it still remains an easy and simple method to make a number of adjustments in tractors (Purcell 1980). Clark and Corlett (1995) and Weimer (1993) demonstrated the use of hand–levers. Their main conclusion was that hand–levers may be used when high forces or large displacement are involved or when multidimensional movements of controls are required. Furthermore, they categorized hand–levers as being either rigid or spring–loaded and reached the conclusion that spring–loaded levers are preferred because their control positions can be determined visually.

On the other hand, they showed that due to the fact that hand–levers have a limited range of movement, they are usually unsatisfactory for precise positioning over a wide range of adjustments. The disadvantage mentioned can explain the partial, or in some cases the total, replacement of hand–levers as a primary control from old to modern tractors.

A comprehensive guide regarding hand–lever design was given by Clark and Corlett (1995). In this guide, three factors are presented as important when operating a hand–lever. These are the displacement, separation, and activation force.

Weimer (1993) suggested a maximum displacement of 355 mm (14 in), a value that has been accepted by the majority of the authors listed below and it is still in use in the design industry.

Early work by Van Cott and Kinkade (1972) defined the minimum separation of hand–levers at the value of 50 mm (2 in). Similarly to the previous dimension, this value is a very common recommendation and today it is strictly used in control arrangement in a tractor cab (Purcell 1980).

Later, NASA (1995) published a guide in which the proper values of activation forces for hand–levers were categorized according to their type (e.g., one hand push–pull levers, two handed push–pull levers, one handed right–left lever). The maximum resistance for a hand push–pull lever, mainly met in tractors, was 20 kg (44 lbf) based on the maximum arm strength of the 5^{th} male percentile. The 5^{th} male percentile was chosen intentionally by NASA in order to accommodate a bulky member of the potential operator population. A closer examination of the maximum activation force values given from other sources shows that there are also some different suggestions. An explanation for this discrepancy in values can be the fact that some authors probably did not consider the maximum arm strength of the 5^{th} male percentile which is 19 kg (42 lbf) as given by NASA (1995), Van Cott and Kinkade (1972), Weimer (1993), and Purcell (1980).

Design recommendations concerning the displacement, separation, and activation force for hand–levers are given in Table 4.6. A careful review of Table 4.6 shows that acceptable values for most of the authors are:

- Displacement: ≤ 355 mm (14 in)
- Separation: ≥ 100 mm (4 in)
- Activation Force: ≤ 16 kg (35 lbf)

Table 4.6 Various recommended Hand–Lever sizes which facilitate optimal control for an operator based on 5th male percentile

Author	Year of Publication	Displacement mm (in)	Separation Mm (in)	Activation Force Kg (lbf)
Corlett & Clark	1995	≤ 355 (14)	50–100 (2–4)	≤ 16 (35)
Van Cott & Kinkade	1972	≤ 355 (14)	50–100 (2–4)	≤ 14–23 (30–50)
Grandjean	1988	≤ 350 (13.8)	N/A	≤ 13 (29)
Sanders & McCormick	1993	≤ 355 (14)	OPT* 100 (4)	9–45 (20–100)
NASA–STD–3000	1995	N/A	N/A	≤ 22 (50)
MIL–STD–1472F	1999	≤ 355 (14)	OPT 100 (4)	0.9–14 (2–30)
Pheasant	1986	OPT 100–200 (4–8)	OPT 100 (4)	N/A
Weimer	1993	≤ 355 (14)	OPT 100 (4)	≤ 13 (29)
Konz	1990	N/A	N/A	N/A

*Optimum values

Investigations by Dupuis et al. (1955) and by Dupuis (1957), dealt with the pulling force that can be exerted from a seated person, when the hand is at various distances from a point called Seat Reference Point (SRP) as defined by Purcell (1980). Figure 4.1 illustrates the serious reduction in effective force as the arm is flexed when it is pulled toward the body. The maximum force that can be exerted by pulling is about 50 kg, within a distance of 570 to 660 mm (22.4 to 26 in), covering a 90° envelope forward from the seat reference point (SRPo). As a result, this distance defines the optimum location of a lever control such as a hand brake.

At this point, the importance of the proper location of hand–levers in a tractor cab must be mentioned. All the hand–levers must be located within the ideal distance as Dupuis et al. (1955) showed. The specific arrangement of controls will be beneficial for the operator, especially during long working hours because his upper body will be working while spending the minimum effort to make the adjustments as the hand–levers will be located in his 'convenience zone'.

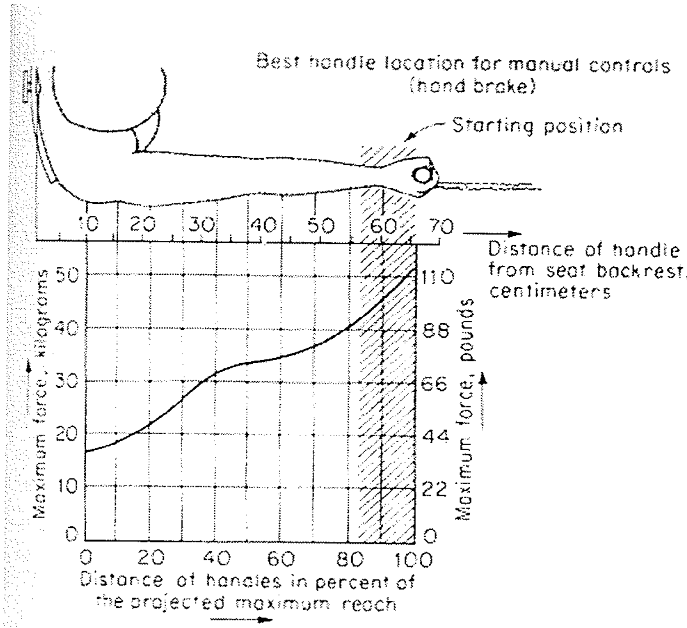

Figure 4.1 Relationship between maximum pulling force (such as on a hand brake) and location of control handle
(Source: Dupuis 1955)

4.1.7 Steering Wheel

The steering wheel is the main control that is found in every tractor. Purcell (1980) describes it as the most important control in the tractor cab. He mentions that the driver's left hand must be available for steering at all times. Special consideration is given in its following three dimensions: the diameter, rim thickness, and angle to the horizontal plane.

Generally, according to Pheasant (1986), a 380 mm diameter is at the lower limits of acceptability and 400–440 mm (16–17.3 in) would probably be better, giving additional torque to the weaker driver. In addition, an ideal rim thickness ranges from

20 to 35 mm (0.8–1.25 in) for heavy machines such as tractors. Studies conducted by Howe et al. (1992) proved that a more vertical wheel might be more easily accommodated. However, at the same time he showed that the maximum force (torque) was exerted on a horizontal wheel, although paradoxically the speed of rotation was maximal when the wheel was vertical. He, therefore, recommended that the axis of the wheel (i.e., the steering column) should be 40–60° to the horizontal plane, in which position 70% of the maximum force can be exerted. This concept is also supported by other design specialists (Van Cott and Kinkade 1972; Konz 1990; Morgan 1963, and Weimer 1993).

Table 4.7 illustrates different design recommendations concerning the diameter, rim thickness, and angle to the horizontal plane for steering wheel. According to the following table, most of the authors agree with the recommendations summarized below:

- Diameter: 400–510 mm (15.7–20 in)
- Rim Thickness: 19–32 mm (0.75–1.25 in)
- Angle to the Horizontal Plane: 40°–60°

Table 4.7 Various recommended Steering Wheel sizes which facilitate optimal control for an operator

Author	Year of Publication	Diameter mm (in)	Rim Thickness mm (in)	Angle to the Horizontal Plane (°)
Corlett & Clark	1995	200–500 (8–19.7)	20–50 (0.8–2)	N/A
Van Cott & Kinkade	1972	381–457 (15–18)	19–50 (0.75–2)	30–60
Grandjean	1988	180–500 (7–19.7)	N/A	N/A
Sanders & McCormick	1993	180–533 (7–21)	19–50 (0.75–2)	N/A
NASA–STD–3000	1995	N/A	N/A	N/A
MIL–STD–1472F	1999	400–510 (16–20)	19–32 (0.75–1.25)	OPT 45
Pheasant	1986	OPT* 380–440 (15–17.3)	OPT 20–40 (0.8–1.6)	OPT 50–60
Weimer	1993	180–530 (7–21)	20–50 (0.8–2)	30–60
Konz	1990	400–510 (15.7–20)	20–32 (0.8–1.25)	OPT 45

*Optimum values

4.1.8 Multifunction Hand Controls

A new method used by tractor manufacturers to give operators flexibility during the long hours of operation while improving the level of comfort is the existence of a multifunction hand control. This type of control can be characterized as the 'result' of the current advances in technology that have made systems more complex and have endowed them with more functions. A more complicated example showing the current application of the multifunction hand controls is in an aircraft. A pilot must be able to control various aircraft functions at the same time in a demanding environment and this is possible by using this type of control. Today, the use of a multifunction control in the aircraft cockpit is considered a basic requirement. Wierwille (1984) points out that the design of multifunction hand controls is based on the following principles:

- The operator should not have to observe the control to operate it.
- The hand should remain in contact with the primary controls throughout critical operations of the system.
- Any auxiliary controls should be able to be activated without loss of physical contact with the primary controls.

Studies conducted by Purcell (1980) have shown that multifunction controls require more complicated instructions and a longer learning period than the single purpose types. Moreover, he notes that they are only effective in increasing work efficiency when the operator becomes an expert on the machine and reacts instinctively.

Unfortunately, little research has been conducted on multifunction controls, and, therefore, it is not known, for example, the maximum number of functions that can be efficiently controlled by an operator. As Wierwille (1984) suggests, comprehensive testing is mandatory whenever a multifunction control is used in a system.

4.2 Incorporation of the Frequency of Use for Categories of Controls in the Model

4.2.1 Rank of the Five Control Categories According to their Frequency of Use

A questionnaire was distributed, asking each farmer to rank the categories of controls according to their frequency of use during a tillage operation. Control categories were ranked starting with the lowest frequency of use. Although surveys were completed individually, all ten operators provided an identical ranking (Table 4.8).

Table 4.8 Survey data analysis–Final rank of control categories in terms of their frequency of use*

Farmers	Steering Wheel	Controls related to the functioning of the implement	Controls related to the motion of the tractor	Controls related to the internal environment	Controls related to the external environment
Farmer 1	5	4	3	2	1
Farmer 2	5	4	3	2	1
Farmer 3	5	4	3	2	1
Farmer 4	5	4	3	2	1
Farmer 5	5	4	3	2	1
Farmer 6	5	4	3	2	1
Farmer 7	5	4	3	2	1
Farmer 8	5	4	3	2	1
Farmer 9	5	4	3	2	1
Farmer 10	5	4	3	2	1
Average	50/10=5	40/10=4	30/10=3	20/10=2	10/10=1
Final Rank	**5**	**4**	**3**	**2**	**1**

* 1 refers to the lowest rank
5 refers to the highest rank

The steering wheel was ranked as the most frequently used control. In decreasing frequency of use, farmers ranked the controls as follows: controls related to the functioning of the implement, controls related to the motion of the tractor, controls related to the internal environment, and controls related to the external environment. Based on this rank the relative frequency of use can be derived. The procedure is described in the following Chapter.

4.2.2 Mathematical Description of the Four Steps Used to Calculate the Relative Frequency of Use

In the numerical index presented, the ergonomic score for each type of control is multiplied by the relative frequency of use calculated for that type of control. The relative frequency of use values were derived from the frequency of use for the various categories of controls through a mathematical procedure which is described below.

In general, the relative frequency of use for each control type is correlated directly with its most important design characteristics through the relevant sub–equation. Thus, the more that a specific type of control is used, the more its design characteristics will contribute to the determination of its ergonomic score. Theoretically, high correlation (i.e., scores close to 1) means that the overall design of a specific type of control is better.

The procedure that has been selected to determine the relative frequency of use consists of four steps and is described below.

First step

Controls are categorized in five categories according to their general function:

- cc_1 = control category 1 = Steering Wheel
- cc_2 = control category 2 = Controls related to the functioning of the implement
- cc_3 = control category 3 = Controls related to the motion of the tractor
- cc_4 = control category 4 = Controls related to the internal environment
- cc_5 = control category 5 = Controls related to the external environment

Second step

A tractor cab is reviewed in terms of its total number of different types of controls present per control category.

- $\sum cc_1$ = Total number of steering wheels

  cc_1= control category 1

- $\sum cc_2 = (\sum c_{1,2} + \sum c_{2,2} + \sum c_{3,2} + \sum c_{4,2} + \sum c_{5,2} + \sum c_{6,2})=$

  Total number of controls related to the functioning of the implement

$\sum c_{1,2}$= Total number of Rotary Switches related to the functioning of the implement

$\sum c_{2,2}$= Total number of Toggle Switches related to the functioning of the implement

$\sum c_{3,2}$= Total number of Rocker Switches related to the functioning of the implement

$\sum c_{4,2}$= Total number of Knobs related to the functioning of the implement

$\sum c_{5,2}$= Total number of Push Buttons related to the functioning of the implement

$\sum c_{6,2}$= Total number of Hand–Levers related to the functioning of the implement

- $\sum cc_3 = (\sum c_{1,3} + \sum c_{2,3} + \sum c_{3,3} + \sum c_{4,3} + \sum c_{5,3} + \sum c_{6,3})=$

  Total number of controls related to the motion of the tractor

$\sum c_{1,3}$= Total number of Rotary Switches related to the motion of the tractor

$\sum c_{2,3}$= Total number of Toggle Switches related to the motion of the tractor

$\sum c_{3,3}$= Total number of Rocker Switches related to the motion of the tractor

$\sum c_{4,3}$= Total number of Knobs related to the motion of the tractor

$\sum c_{5,3}$= Total number of Push Buttons related to the motion of the tractor

$\sum c_{6,3}$= Total number of Hand–Levers related to the motion of the tractor

- $\sum cc_4 = (\sum c_{1,4} + \sum c_{2,4} + \sum c_{3,4} + \sum c_{4,4} + \sum c_{5,4} + \sum c_{6,4})=$

  Total number of controls related to the internal environment

$\sum c_{1,4}$= Total number of Rotary Switches related to the internal environment

$\sum c_{2,4}$= Total number of Toggle Switches related to the internal environment

$\sum c_{3,4}$= Total number of Rocker Switches related to the internal environment

$\sum c_{4,4}$= Total number of Knobs related to the internal environment

$\sum c_{5,4}$= Total number of Push Buttons related to the internal environment

$\sum c_{6,4}$= Total number of Hand–Levers related to the internal environment

- $\sum cc_5 = (\sum c_{1,5} + \sum c_{2,5} + \sum c_{3,5} + \sum c_{4,5} + \sum c_{5,5} + \sum c_{6,5})$=

  Total number of controls related to the external environment

$\sum c_{1,5}$= Total number of Rotary Switches related to the external environment

$\sum c_{2,5}$= Total number of Toggle Switches related to the external environment

$\sum c_{3,5}$= Total number of Rocker Switches related to the external environment

$\sum c_{4,5}$= Total number of Knobs related to the external environment

$\sum c_{5,5}$= Total number of Push Buttons related to the external environment

$\sum c_{6,5}$= Total number of Hand–Levers related to the external environment

Third step

The relative frequency of use for the different control types per control category is determined (the steering wheel control category is not considered i.e., cc_1= 0).

$Fc_{1,2}= [\sum c_{1,2}/ \sum cc_2] \cdot 10$ $Fc_{1,3}= [\sum c_{1,3}/ \sum cc_3] \cdot 10$ $Fc_{1,4}= [\sum c_{1,4}/ \sum cc_4] \cdot 10$ $Fc_{1,5}= [\sum c_{1,5}/ \sum cc_5] \cdot 10$

$Fc_{2,2}= [\sum c_{2,2}/ \sum cc_2] \cdot 10$ $Fc_{2,3}= [\sum c_{2,3}/ \sum cc_3] \cdot 10$ $Fc_{2,4}= [\sum c_{2,4}/ \sum cc_4] \cdot 10$ $Fc_{2,5}= [\sum c_{2,5}/ \sum cc_5] \cdot 10$

$Fc_{3,2}= [\sum c_{3,2}/ \sum cc_2] \cdot 10$ $Fc_{3,3}= [\sum c_{3,3}/ \sum cc_3] \cdot 10$ $Fc_{3,4}= [\sum c_{3,4}/ \sum cc_4] \cdot 10$ $Fc_{3,5}= [\sum c_{3,5}/ \sum cc_5] \cdot 10$

$Fc_{4,2}= [\sum c_{4,2}/ \sum cc_2] \cdot 10$ $Fc_{4,3}= [\sum c_{4,3}/ \sum cc_3] \cdot 10$ $Fc_{4,4}= [\sum c_{4,4}/ \sum cc_4] \cdot 10$ $Fc_{4,5}= [\sum c_{4,5}/ \sum cc_5] \cdot 10$

$Fc_{5,2}= [\sum c_{5,2}/ \sum cc_2] \cdot 10$ $Fc_{5,3}= [\sum c_{5,3}/ \sum cc_3] \cdot 10$ $Fc_{5,4}= [\sum c_{5,4}/ \sum cc_4] \cdot 10$ $Fc_{5,5}= [\sum c_{5,5}/ \sum cc_5] \cdot 10$

$Fc_{6,2}= [\sum c_{6,2}/ \sum cc_2] \cdot 10$ $Fc_{6,3}= [\sum c_{6,3}/ \sum cc_3] \cdot 10$ $Fc_{6,4}= [\sum c_{6,4}/ \sum cc_4] \cdot 10$ $Fc_{6,5}= [\sum c_{6,5}/ \sum cc_5] \cdot 10$

Fourth step

The last step includes the calculation of the relative frequency of use for the different control types (the steering wheel control category is not considered i.e., $cc_1= 0$).

$$Fc_1= [4Fc_{1,2} + 3Fc_{1,3} + 2Fc_{1,4} + Fc_{1,5}]$$

$$Fc_2= [4Fc_{2,2} + 3Fc_{2,3} + 2Fc_{2,4} + Fc_{2,5}]$$

$$Fc_3= [4Fc_{3,2} + 3Fc_{3,3} + 2Fc_{3,4} + Fc_{3,5}]$$

$$Fc_4= [4Fc_{4,2} + 3Fc_{4,3} + 2Fc_{4,4} + Fc_{4,5}]$$

$$Fc_5= [4Fc_{5,2} + 3Fc_{5,3} + 2Fc_{5,4} + Fc_{5,5}]$$

$$Fc_6= [4Fc_{6,2} + 3Fc_{6,3} + 2Fc_{6,4} + Fc_{6,5}]$$

4.3 Incorporation of the Human Factors Considerations in the Model

The consideration and the inclusion of the four ergonomic factors is a main component of the model. These factors are incorporated in the model by following the same proportional concept used for the determination of the ergonomic score for the various control types.

In each ergonomic factor two weight values are given. The first weight value (i.e., Ea), which is equal to their average, is the same for the four factors and the second weight value (i.e., WPc, WSc, WFr, and WLc), which incorporates the expert weight, emphasizes their individually relevant importance in the tractor environment. The first weight value is used in order to give more accurate results as any significant high or low score that resulted from each factor can influence the ergonomic factor average and consequently give more accurate weight distribution to the final model value.

4.3.1 Placement of Controls (Pc)

Placement of controls in a tractor cab is based on a principle which states that all the controls which require accurate manipulation; should be grouped on the right–hand side of the operator, leaving his left hand available for steering at all times (Purcell 1980). A review of different control layouts in tractors confirms that designers still follow this principle. Consequently, the ergonomic score for the placement of controls is calculated as the proportion of controls present on the right–hand side of the operator. This proportional factor can take any value between 0 and 1, with 1 being defined as the maximum value. In this case, all the controls will be located on the right–hand side of the operator. On the other hand, a value of 0 means that all the controls will be located on the left–hand side of the operator.

4.3.2 Suitability of Controls (Sc)

The suitability of controls refers to the compatibility between the actions required by the system (controls) and the intentions of the possible user (driver). Specifically, the ergonomic score for the suitability of controls is calculated as the proportion of controls where mode of action is appropriate to function. Similarly to the placement of controls, this proportional factor, can take any value between 0 and 1, with 1 being defined as the maximum value. In this case, the mode of all control's action will be appropriate to function. On the other hand, a value of 0 means that the mode of all control's action will not be appropriate to function.

The results from a study regarding the general suitability of controls for different types of operation, conducted by Corlett and Clark (1995) were considered to estimate the proportional value.

4.3.3 Functional Reach (Fr)

The functional reach emphasizes the Principle of Importance giving it a key role in the model. Specifically, the ergonomic score for the functional reach is calculated as the proportion of controls present within a radius of 750 mm, covering a 180° envelope, in front of the operator from the 'Seat Reference Point' (SRPo). Its values ranged from 0 to 1, with 1 being defined as the maximum value. When all the controls are located within the functional reach of the operator (i.e., within a radius of 750 mm), the proportional factor value is 1. Otherwise, when none of the controls are located within the functional reach of the operator (i.e., within a radius of 750 mm), the proportional factor value is 0.

4.3.4 Control Labelling (Lc)

In control labelling, consideration is given to the labels or other indications (e.g., icons, symbols) and the total number of colours that are used. The ergonomic score for the control labelling is calculated as the average of the proportion of controls having an associated title (e.g., a label above controls) or indication (e.g., icon, symbol) and also depends on the total number of colours that are used in the control layout.

The overall ergonomic score for the control labelling is calculated from the following equation (Eq. 4.2).

$$Lc = (Lc1 + Lc2)/2 \qquad \text{(Eq. 4.2)}$$

where:

Lc = ergonomic score for the control labelling,

Lc1= proportion of controls having an associated title (e.g., a label above controls) or indication (e.g., icon, symbol),

Labels: the height of numerals and letters must be at least 2.5 mm,

Icons and symbols: consideration of ASABE S304.7 (2000).

Lc2= colour –coding:

Lc2= 1, if up to four colours are used; or

Lc2= 0.3, if more than four colours are used.

4.3.5 Weight Determination of the Four Ergonomic Factors According to their Relative Importance

Five professional ergonomists participated in a survey in which they were asked to distribute 100 points among the four factors according to their relative importance (Table 4.9).

Table 4.9 Survey data analysis – Final weight of the four ergonomic factors

Ergonomic Experts	**Placement of Controls (Pc)**	**Functional Reach (Fr)**	**Suitability of Controls (Sc)**	**Labelling of Controls (Lc)**
Expert 1	30	10	20	40
Expert 2	20	40	30	10
Expert 3	30	20	40	10
Expert 4	30	15	15	40
Expert 5	40	40	15	5
Sum	*150/250*	*125/250*	*120/250*	*105/250*
Final Weight	**0.6**	**0.5**	**0.48**	**0.42**

A review of the table above shows that placement of controls was considered to be the most important factor, having a weight value of 0.6. Experts mentioned that until the fully electronic controls interface tractor cab appears, the location of controls is critical for a safe and cohesive driving environment. The different groups of electronic controls, which consist of digital push buttons located in a touch screen, would possibly eliminate problems related to the proper location of the controls.

The second highest weighted factor was the functional reach, presenting a weight value of 0.5. All the experts agreed that it is essential for the operator to maintain a comfortable seated position in the cab during long durations of operation. Therefore, with a less than optimal functional reach, the operator would have to assume less comfortable positions which could lead to fatigue or negative physical symptoms.

The third highest weighted factor was the suitability of controls, having a weight value of 0.48. Experts responded that this is a basic requirement for the overall design of controls. Control–movement compatibility should definitely be met because if the mode of action of controls is not appropriate for functions, operation will be prone to error. In addition, two experts related the suitability of controls with the safety operation by underling the fatigue and physical problems that can be experienced by an operator.

The least weight was given to the control labelling, providing a value of 0.42. Experts mentioned that labelling of controls is of less importance in a tractor environment. The only general consideration provided was that controls should follow the ASABE standards for colour assignment and should additionally employ differentiation of controls by size, shape, or symbols to allow user selection and differentiation either visually or by feel. The explanation that was given regarding its relative importance was based on the fact that tractor operators are very experienced and typically operate tractors over long durations. As a result, the labelling of controls has less impact on performance. It is likely that the operators will access individual controls by memory of their location and reach distance, rather than by labelling. However, some type of labelling or training manual is needed to initially familiarize new operators to the cab.

In summary, it must be noted, that the results derived from the survey depict the ergonomists opinion regarding the relative importance of the four ergonomic factors for a control layout of a tractor. Any other application of these results in a different environment should be carefully applied and analyzed.

4.3.5.1 Analysis of the Weight Determination of the Four Ergonomic Factors

A careful examination of the table above shows that the sum of each category has been divided by 250. This number has been proved to be very important for the determination of the final model value.

A number of calculations demonstrated that divisions with different numbers have given different weights for each ergonomic factor which were not desirable in terms of their overall weight distribution in the final model value. Given that the 'Index of Functionality' consists of the sum of the following factors (Design Considerations on Control Types + Ergonomic Factors + Sw + Mc). A number of divisions that were conducted with values bigger than 250 showed that the final model value included remarkably more overall weight distribution from the ergonomic factors rather than the different control types, the steering wheel, and the multifunction control.

On the other hand, divisions that were conducted with values smaller than 250 showed that the final model value included remarkably more overall weight distribution from the different control types, the steering wheel, and the multifunction control rather than the ergonomic factors.

Our intention was that the final model value should be influenced in terms of weight distribution as follows: first from the ergonomic factors, second from the multifunction control, third from the different control types, and fourth from the steering wheel. Moreover, their weight distribution should present a normal allocation. This means that the four factors not only should have the order described above, but also their weight distribution values should not present a significant gap among them. These requirements were satisfied by the chosen value of 250.

4.4 The Index of Functionality

The numerical index developed is called the 'Index of Functionality' (*IF*). Its final form is presented below (Eq. 4.3). It can take any value between 0 and 1, with 1 being defined as the optimum value in terms of the functionality of an entire control panel.

$$I_F=\frac{(F_{Sr}\cdot Sr)+(F_{St}\cdot St)+(F_S\cdot S)+(F_{Kb}\cdot Kb)+(F_{Bp}\cdot Bp)+(F_L\cdot L)+(Ea)\cdot[(0.6\cdot Pc)+(0.48\cdot Sc)+(0.5\cdot Fr)+(0.42\cdot Lc)]+Sw+Mc}{\sum^{n} F+4} \quad \text{(Eq. 4.3)}$$

where:

Sr= ergonomic score for rotary switches= [(Sr1+Sr2+Sr3+Sr4)/4],

F_{Sr}= relative frequency of use for rotary switches,

St= ergonomic score for toggle switches= [(St1+St2)/2],

F_{St}= relative frequency of use for toggle switches,

S= ergonomic score for rocker switches= [(S1+S2+S3)/3],

F_S= relative frequency of use for rocker switches,

Kb= ergonomic score for knobs= [(Kb1+Kb2+Kb3)/3],

F_{Kb}= relative frequency of use for knobs,

Bp= ergonomic score for push buttons= [(Bp1+Bp2)/2],

F_{Bp}= relative frequency of use for push buttons,

L= ergonomic score for hand–levers= [(L1+L2+L3+L4)/4],

F_L= relative frequency of use for hand–levers,

Sw= ergonomic score for steering wheel= [(Sw1+Sw2+Sw3+Sw4)/4],

Mc= ergonomic score for multifunction hand control,

Pc= placement of controls,

Sc= suitability of controls,

Fr= functional reach,

Lc= control labelling= [(Lc1+Lc2)/2],

Ea= ergonomic factors average= [(Pc+Sc+Fr+Lc)/4]; and

n= total number of control types (maximum value n=6, excluding Sw and Mc).

For the propose of this thesis, the 'Index of Functionality' was applied to a variety of agricultural tractors of varying age to identify any ergonomic improvements that have been made by manufacturers over the past several decades. In the next chapter, the results that will be presented show that this numerical index effectively recognized the ergonomic gap that exists between modern and old tractors.

5. APPLICATION OF THE MODEL

Adding new technology and changing the design of the workstations may not necessarily make modern tractors ergonomically better than previous versions that lacked the new technology and design. The design of a complex man–machine system, such as the control panel of a tractor, often involves making trade–offs and compromises to meet customer requirements and staying within cost and schedule limitations. However, modern tractor manufacturers, based on the principle of 'user–centered' design, give particular emphasis to the incorporation of the human factors into the design of the tractor cab. A careful review of a number of modern tractor workstations is a strong confirmation that the understanding of human factors issues has developed in the right direction. Safe and fully accessible work environments are two representative words that describe modern tractor cabs. In order to validate the model, data were collected from six old and six modern tractor workstations. They were evaluated to determine whether the model would correctly recognize improvements that have occurred in the ergonomic design of tractor control layouts over the past 20 years. In the following paragraphs, the tractor control layouts chosen for this study and the results derived from the application of the model will be presented.

5.1 The Procedure for Collecting the Data

The 'Index of Functionality' was tested in 12 agricultural tractor cabs. Six of them were modern tractor cabs having a manufacturing date from 2003 to 2005. The other six were old tractor cabs having a manufacturing date from 1975 to 1981. All of the tractors were medium size class tractors and they had 4 Wheel Drive except the last two old tractors. The materials that were used to take the various measurements are described below:

- A measuring tape. It was used to measure the different selected dimensions of control types and the height of numerals and letters used in control labelling (Lc),
- A dynamometer. It was used to measure the activation force for the hand–levers and for the multifunction hand controls,
- The manual of each tractor. It was used to discover the angle that the steering wheel made with the horizontal plane,
- The ASABE (American Society of Agricultural and Biological Engineers) standard S304.7. It was used for the consideration of the standard icons and symbols in control labelling (Lc),
- A rope with a length of 750 mm. It was used to determine the number of controls that were included within the functional reach of the operator (Fr). Specifically, the distance of 750 mm was measured from the 'Seat Reference Point' (SRPo) which according to the U.S. Department of Defence (1976) is located in the median longitudinal plane of the seat where the compressed seat plane i.e., 'Seat Reference Plane' (SRPl) and the vertical reference line intersect (Figure 5.1),
- A rope with a length of 660 mm. It was used to determine the number of the hand–levers that were located within 570 to 660 mm covering a 90° envelope in front of the 'Seat Reference Point' (SRPo) for both hands; and
- A table generated by Corlett and Clark (1995) which refers to the general suitability of controls for different types of operation

(Chapter 2.4). It was used to identify the number of controls where the mode of action was appropriate to function.

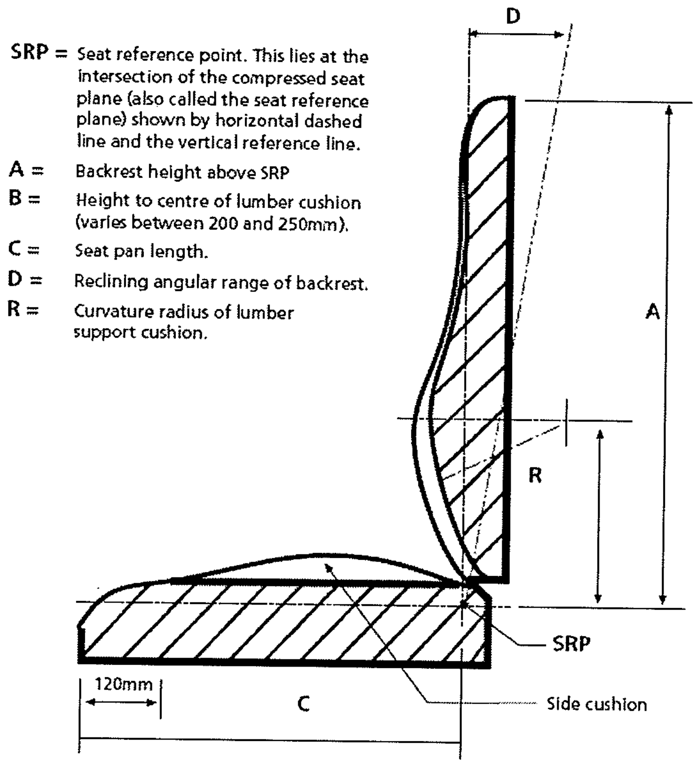

Figure 5.1 Location of the Seat Reference Point (SRPo)–Seat Reference Plane (SRPl)
(Source: Road Freight Transport Industry 2005)

Having all the mentioned materials available and a data collection sheet for each tractor (appendix B), a comprehensive examination of each tractor cab was conducted and as a result, the necessary values were derived.

In the next pages, an introduction to the tractors and their control layouts that were analysed will be presented.

5.1.1 Control Layout for the John Deere 8220

The new 225–hp 8220 (Figure 5.2) was manufactured in 2004 and its control layout provided the latest technology developments in terms of control design and ergonomic solutions. A characteristic example was the Comfort–Command seat that could swivel 20 degrees right and 15 degrees left to give the driver complete mobility and considerably easier access to the controls.

Figure 5.2 An exterior view of the John Deere 8220

The control console (Figure 5.3) was conveniently located on the right hand–side of the seat and the basic controls (e.g., engine throttle, transmission shifter, hitch, hydraulics, and PTO) were attached to this side in order to be moved with the seat. Thus, the majority of the tractor functions were always within easy reach.

Figure 5.3 An interior view of the John Deere 8220

5.1.2 Control Layout for the Case IH MX 230

The new 190–hp MX 230 (Figure 5.4) was manufactured in 2005. High interest presented the large volume of the cab (i.e., 3.1 m^3) and the glass area of 6.3 sq. m which provided to the driver a 360–degree visibility.

Figure 5.4 An exterior view of the Case IH MX 230

The convenient right–hand armrest controls (Figure 5.5) were characterized by their nearly effortless operation. Similar to the John Deere tractor, the control console was integrated with the seat and as a result the controls remained within easy reach whether the seat was swivelled, raised or lowered.

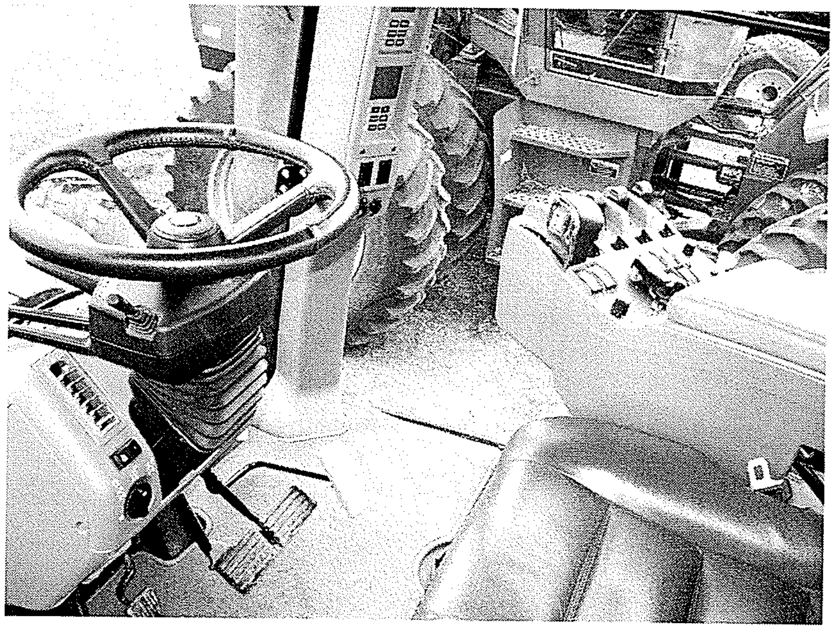

Figure 5.5 An interior view of the Case IH MX 230

5.1.3 Control Layout for the Buhler–Versatile 2210

The new 210–hp 2210 was manufactured in 2005 (Figure 5.6).

Figure 5.6 An exterior view of the Buhler–Versatile 2210

The most important controls (i.e., the hydraulic controls along with the throttle, gear selectors and cruise–control switches) were located on a side console by the operator's right hand (Figure 5.7). The throttle and cruise–control switches were placed in a particularly convenient location and could be adjusted with a thumb or finger without moving the elbow from the seat's armrest.

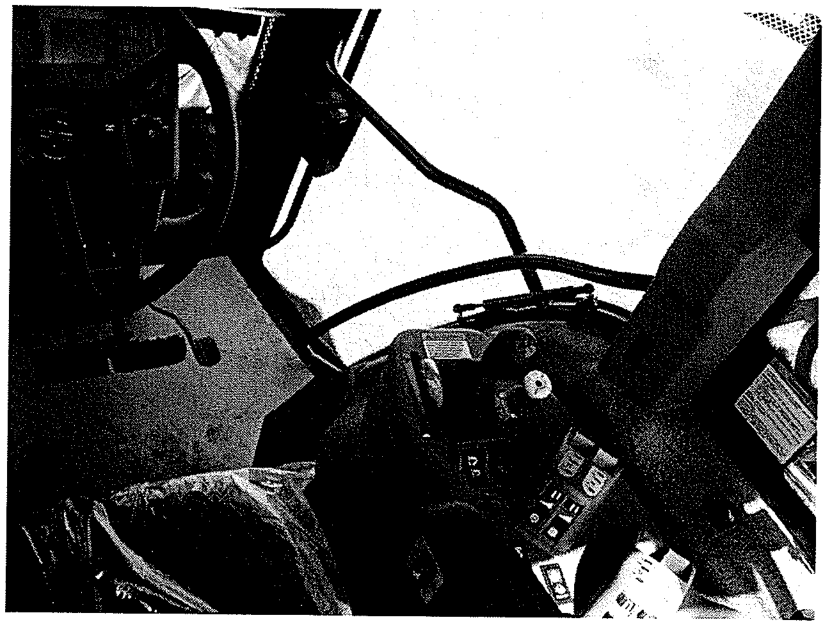

Figure 5.7 An interior view of the Buhler–Versatile 2210

5.1.4 Control Layout for the New Holland TG 285

The new 240–hp TG 285 was manufactured in 2003 (Figure 5.8).

Figure 5.8 An exterior view of the New Holland TG 285

The large workstation to the left side held the important controls including the transmission lever, throttle and hydraulic remotes at the end of driver's right–hand arm rest (Figure 5.9).

Figure 5.9 An interior view of the New Holland TG 285

5.1.5 Control Layout for the Fendt 920 Vario

The new 210–hp 920 Vario was manufactured in 2004 (Figure 5.10).

Figure 5.10 An exterior view of the Fendt 920 Vario

The specific tractor cab was equipped with a pioneer innovation named Variotronic which is the first system of its kind that integrates all work and control functions within one communication unit. Within this unit, the joystick is the main control element in which all driving functions, plus hydraulics and PTO, can be controlled (Figure 5.11).

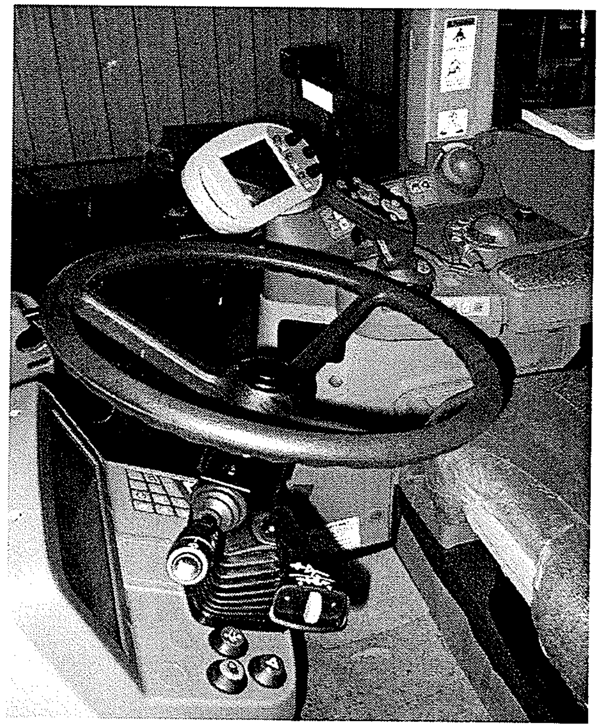

Figure 5.11 An interior view of the Fendt 920 Vario

5.1.6 Control Layout for the Caterpillar Challenger MT665B

The new 220–hp MT665B was manufactured in 2005 (Figure 5.12).

Figure 5.12 An exterior view of the Caterpillar Challenger MT665B

Its control layout included a modern right–hand control console with controls organized by function. The cab was equipped with an armrest which had an integrated screen, joystick, and controls for adjusting a variety of operations including hydraulic functions, front and rear linkage, PTO, cruise control, and powershift (Figure 5.13).

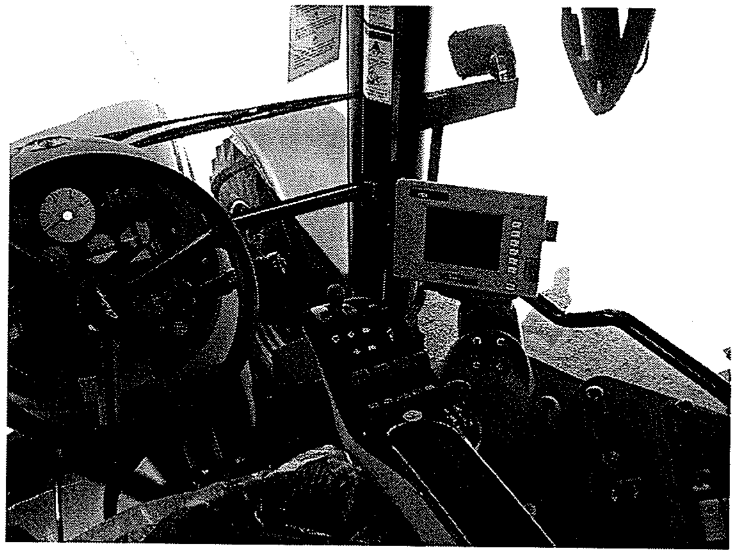

Figure 5.13 An interior view of the Caterpillar Challenger MT665B

Furthermore, powershift and controls for functions which are often used have been duplicated in the armrest for ease of operation. Particularly, the functions for drive controls and hydraulic functions were placed on different sides of the armrest to avoid any misuse.

To ensure more options for different types of work, the controls of five proportional valves of the auxiliary hydraulics were split so that two of them were in a crossgate joystick and three were two–way slide potentiometers. For easier operation, the shape and position of the switches made it possible to use several functions without moving the hand from the palm support of the armrest. Finally, the position of the armrest could be adjusted to individually suit each operator.

5.1.7 Control Layout for the Fendt 275 S

This old tractor was manufactured in 1981 (Figure 5.14).

Figure 5.14 An exterior view of the Fendt 275 S

Its control layout was based mainly on seven hand–levers and four knobs (Figure 5.15).

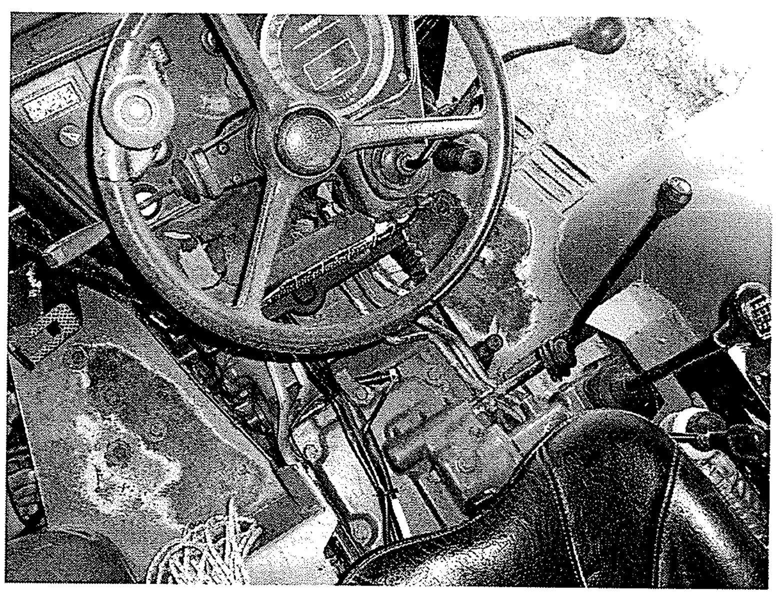

Figure 5.15 An interior view of the Fendt 275 S

Although it included the most control types and presented the best overall control arrangement compared to the other old tractors, its poor design in terms of control dimensions and location of controls was obvious in a seated position. In addition, the controls were not organized by function and the mechanical steering wheel required more effort to operate the tractor. Finally, the partial lack of labels and symbols contributed to a difficult recognition of controls.

5.1.8 Control Layout for the Hurlimann H–478

This old tractor was manufactured in 1980 (Figure 5.16).

Figure 5.16 An exterior view of the Hurlimann H–478

The 11 hand–levers that were used caused considerable confusion to a seated operator. In addition, only a few controls had the associated labels and symbols and nearly all of them were not located within the operator's functional grip. No armrest was provided and the throttle and the gearshift were placed in a particularly inconvenient location on the right–hand side and at the back of the driver. Moreover, the controls for the front and rear linkage, PTO, and powershift required a high force to be operated. Finally, the effect of the various control movements was unclear and incompatible.

In general, its control layout presented serious omissions related to control design standards and to the overall control arrangement (Figure 5.17).

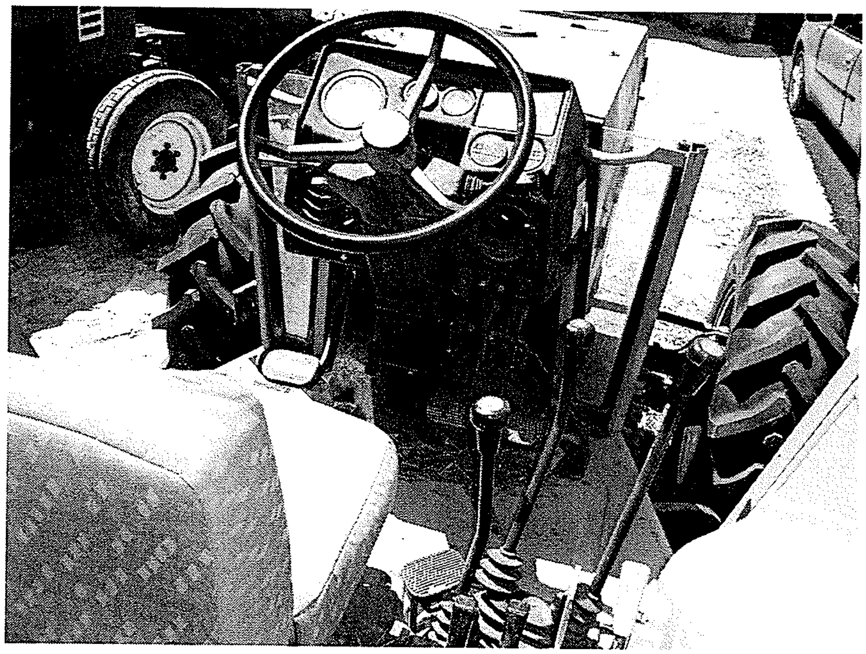

Figure 5.17 An interior view of the Hurlimann H–478

5.1.9 Control Layout for the Agrifull–Fiatagri 65

This old tractor was manufactured in 1978 (Figure 5.18).

Figure 5.18 An exterior view of the Agrifull–Fiatagri 65

Its controls were not organized by function and especially the majority of the hand–levers were positioned in such locations that could cause confusion to the operator (Figure 5.19). The gearshift had an extremely long displacement and the inappropriately placed mechanical steering wheel did not meet the standard dimensions. In addition, the hand–brake required an excessive amount of force to operate it and the majority of the control movements produced an inconsistent and unexpected effect.

The overall impression regarding its controls was that they lacked basic design considerations and in their operation characteristics.

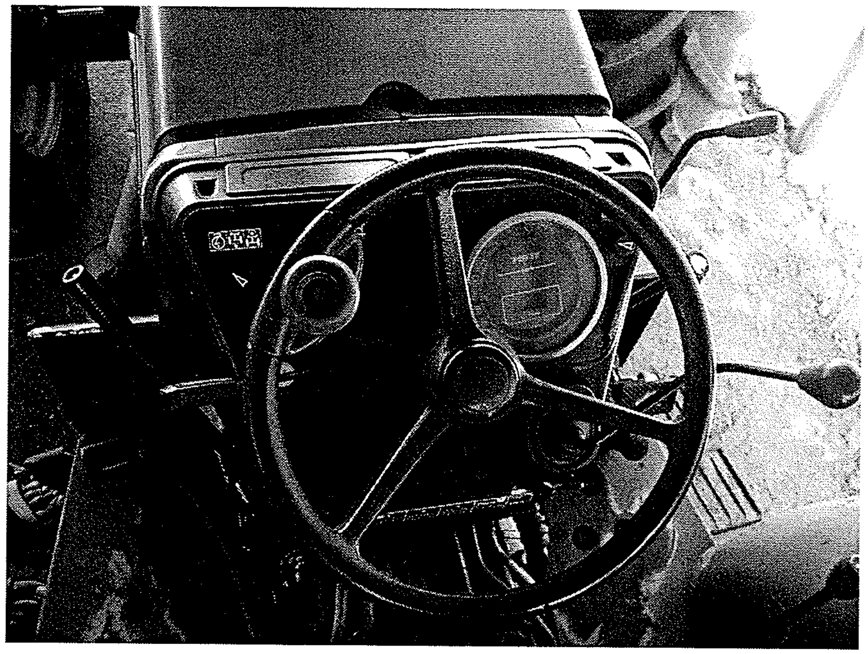

Figure 5.19 An interior view of the Agrifull–Fiatagri 65

5.1.10 Control Layout for the Fiat 640

This old tractor was manufactured in 1975 (Figure 5.20). Its control layout was mainly based on hand–levers and it had the least number of controls of all the tractors that were reviewed (Figure 5.21). The operation of this tractor was very uncomfortable due to the fact that the high back seat was not adjustable. The seat also did not have adjustable suspension for firmness. The hand–levers were not well placed as they were located between the driver's legs. Besides, the controls were confusing for the driver as they did not have a label or symbol.

To conclude, existing controls were not in accordance with the design standards and there was a complete lack of controls for main operations such as drive controls, transmission levers, and differential lock.

Figure 5.20 An exterior view of the Fiat 640

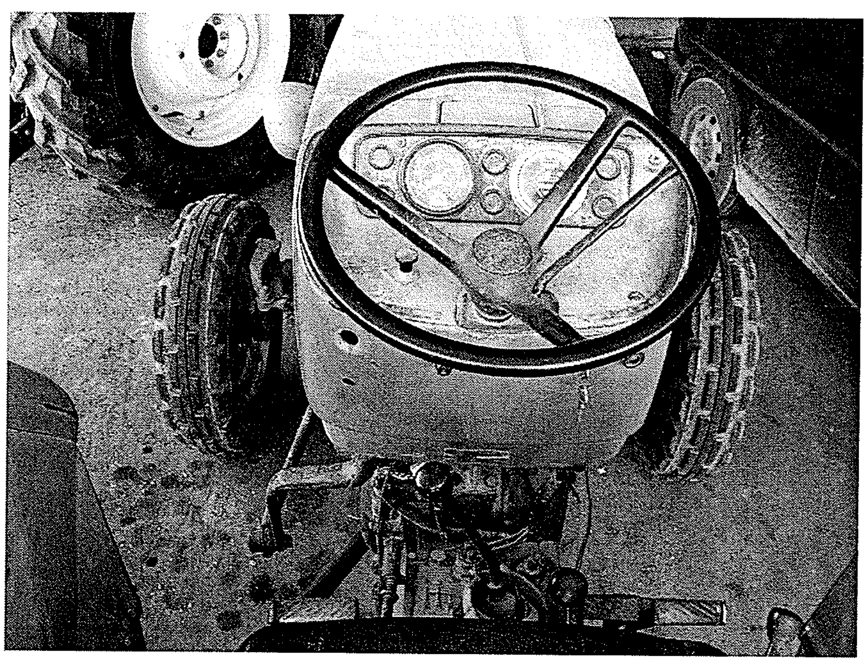

Figure 5.21 An interior view of the Fiat 640

5.1.11 Control Layout for the Steyr 650

This old tractor was manufactured in 1975 (Figure 5.22).

Figure 5.22 An exterior view of the Steyr 650

Similar to Fiat 640 tractor, the number of controls was remarkably low and they were not able to meet the driver requirements for easy and efficient operation (Figure 5.23). There was a seat position control lever mounted under the seat, but its inappropriate position and its unusual length had a negative effect in its operation. The hand brake and the throttle were placed on the right hand–side and outside of the driver's functional reach; therefore, it was difficult for them to be operated in a proper manner. Also, there was a complete lack of any kind of indicators showing the current operation condition of the tractor such as oil pressure indicator, air filter indicator, headlight indicator.

In general, the few existing controls were confusing for the driver as they did not have a label or symbol and all the control movements produced an incompatible effect.

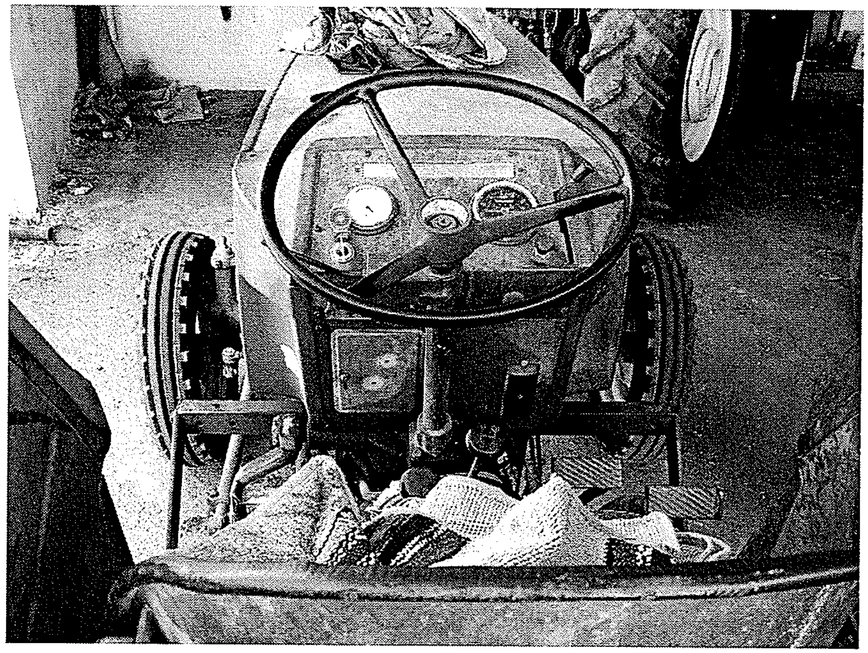

Figure 5.23 An interior view of the Steyr 650

5.1.12 Control Layout for the New Holland S 230

This old tractor was manufactured in 1976 (Figure 5.24).

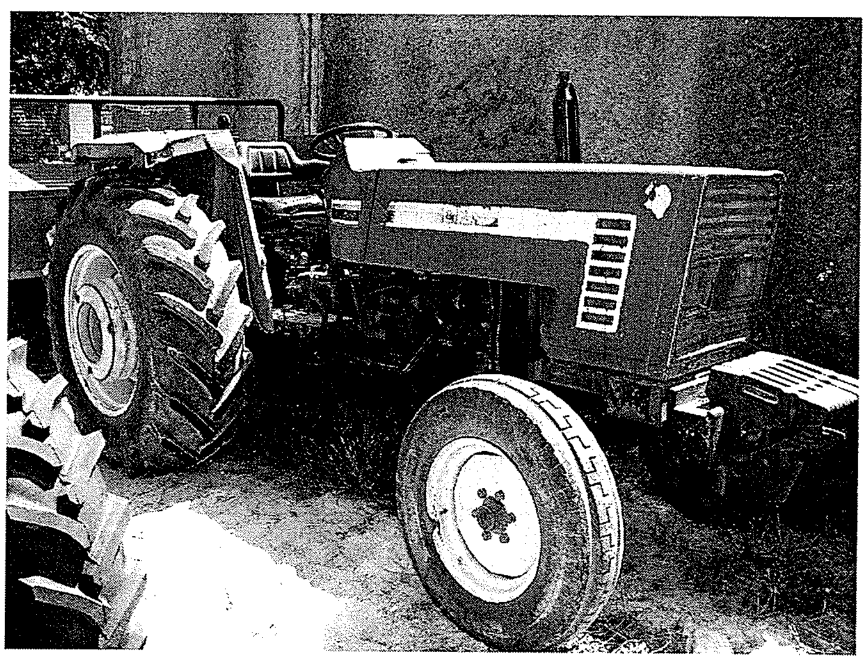

Figure 5.24 An exterior view of the New Holland S 230

An examination of its control layout showed that from an ergonomic perspective there were a number of serious omissions that could be dangerous for the safe operation of the tractor (Figure 5.25).

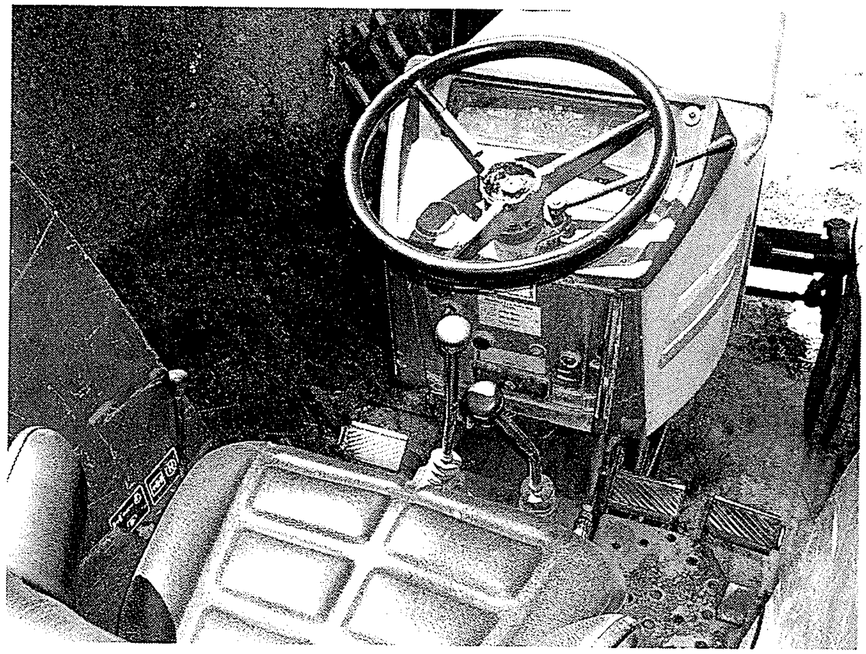

Figure 5.25 An interior view of the New Holland S 230

The transmission was operated with separate forward and reverse hand–levers in front of the driver's seat. Only one of the hand–levers was placed within the driver's functional reach. Both levers had a long displacement and also required a high activation force which was outside the recommended values. In addition, the majority of the control movements produced an inconsistent and unexpected effect causing an insecure feeling for the operator. Moreover, there was a complete lack of any kind of indicators showing the current operation condition of the tractor such as a charge indicator, a fuel indicator, a coolant temperature indicator, an oil pressure indicator, an engine speed–hour indicator.

In general, the control layout of this tractor seemed that it was not in accordance with any control design recommendations and ergonomic solutions required for effortless operation.

5.2 Application of IF to the Control Layouts of the Various Tractors

The 'Index of Functionality' (IF) was applied to the twelve tractor workstations described above. Six of them were modern tractors and the other six were old tractors. A summary of the results regarding the different control types, the total number of controls, and the final value derived from the model for each tractor control layout, are presented below.

5.2.1 IF Application to the John Deere 8220 Control Layout

The John Deere 8220 was based on 7 different control types and a total of 49 controls. The most common control type was the push button with a total of 21 controls. In addition, compared to the other tractor cabs, its workstation had a total number of 10 knobs (Table 5.1).

Table 5.1 Different control types and total number of controls for the John Deere Cab

Control Types for the John Deere 8220	**Number of Controls**
Steering Wheels	1
Buttons	21
Toggle Switches	2
Hand–Levers	2
Knobs	10
Rocker Switches	12
Multifunction Controls	1
Total number of controls	**49**

The ergonomic score for each factor was calculated and the 'Index of Functionality' value for the John Deere 8220 cab was determined (Table 5.2). All the control types, except the buttons, resulted in a high ergonomic score and also all the ergonomic factors satisfied the given requirements to a significant degree. As a result, the John Deere 8220 cab was ranked first in terms of control's accessibility as it derived the highest IF value among the modern tractor cabs.

Table 5.2 Application of Index of Functionality for the John Deere 8220

Factors Considered for the John Deere 8220	**Ergonomic Score • Weight Factor***
Steering Wheel (Sw)	0.81 • 1
Buttons (Bp)	0.49 • 0.41
Toggle Switches (St)	0.75 • 0.07
Hand–Levers (L)	0.62 • 0.07
Knobs (Kb)	0.80 • 0.17
Rocker Switches (S)	0.94 • 0.25
Multifunction Controls (Mc)	1 • 1
Placement of controls (Pc)	0.93 • 0.60
Suitability of controls (Sc)	0.93 • 0.48
Functional reach (Fr)	0.87 • 0.50
Control labelling (Lc)	0.96 • 0.42
IF	**0.83**

*Weight factor for the various control types (chapter 5.3.1)
Ergonomic Factors Weight (chapter 4.3.5)

5.2.2 IF Application to the Case IH MX 230 Control Layout

The Case IH MX 230 was based on 8 different control types and a total of 52 controls. The most common control type, similar to the John Deere, was the push buttons with a total of 16 controls. In addition, its workstation had a total number of 14 rocker switches (Table 5.3).

Table 5.3 Different control types and total number of controls for the Case Cab

Control Types for the Case IH MX 230	Number of Controls
Steering Wheels	1
Buttons	16
Toggle Switches	10
Hand–Levers	2
Knobs	7
Rocker Switches	14
Rotary Switches	1
Multifunction Controls	1
Total number of controls	**52**

The ergonomic score for each factor was calculated and the 'Index of Functionality' value for the Case IH MX 230 was determined (Table 5.4). All the control types, except the buttons and the knobs, resulted in a high ergonomic score and also all the ergonomic factors, except the functional reach, yielded remarkably high scores. The Case IH MX 230 cab was ranked second in terms of control's accessibility as it derived the second highest IF value among the modern tractor cabs.

Table 5.4 Application of Index of Functionality for the Case IH MX 230

Factors Considered for the Case IH MX 230	Ergonomic Score • Weight Factor*
Steering Wheel (Sw)	0.70 • 1
Buttons (Bp)	0.46 • 0.23
Toggle Switches (St)	0.75 • 0.13
Hand–Levers (L)	0.87 • 0.11
Knobs (Kb)	0.52 • 0.12
Rocker Switches (S)	0.80 • 0.37
Rotary Switches (Sr)	0.75 • 0.01
Multifunction Controls (Mc)	1 • 1
Placement of controls (Pc)	0.88 • 0.60
Suitability of controls (Sc)	0.94 • 0.48
Functional reach (Fr)	0.57 • 0.50
Control labelling (Lc)	0.98 • 0.42
IF	**0.75**

*Weight factor for the various control types (chapter 5.3.1)
Ergonomic Factors Weight (chapter 4.3.5)

5.2.3 IF Application to the Buhler–Versatile 2210 Control Layout

The Buhler–Versatile 2210 was based on 7 different control types and a total of 57 controls. The most common control type, similar to the John Deere and the Case IH, was the buttons with a total of 24 controls. Furthermore, its workstation had a total number of 15 rocker switches (Table 5.5).

Table 5.5 Different control types and total number of controls for the Buhler–Versatile Cab

Control Types for the Buhler–Versatile 2210	Number of Controls
Steering Wheels	1
Buttons	24
Toggle Switches	4
Hand–Levers	4
Knobs	8
Rocker Switches	15
Multifunction Controls	1
Total number of controls	57

The ergonomic score for each factor was calculated and the 'Index of Functionality' value for the Buhler–Versatile 2210 was determined (Table 5.6). All the control types, except the buttons and toggle switches, resulted in a high ergonomic score. Also, the high score of each ergonomic factor indicates that they satisfied the given requirements. Thus, the Buhler–Versatile 2210 cab was ranked third in terms of control's accessibility as it derived the third highest IF value among the modern tractor cabs.

Table 5.6 Application of Index of Functionality for the Buhler–Versatile 2210

Factors Considered for the Buhler–Versatile 2210	**Ergonomic Score • Weight Factor***
Steering Wheel (Sw)	0.70 • 1
Buttons (Bp)	0.47 • 0.39
Toggle Switches (St)	0.50 • 0.04
Hand–Levers (L)	0.81 • 0.04
Knobs (Kb)	0.66 • 0.17
Rocker Switches (S)	0.82 • 0.35
Multifunction Controls (Mc)	1 • 1
Placement of controls (Pc)	0.85 • 0.60
Suitability of controls (Sc)	0.98 • 0.48
Functional reach (Fr)	0.85 • 0.50
Control labelling (Lc)	0.63 • 0.42
IF	**0.73**

*Weight factor for the various control types (chapter 5.3.1)
Ergonomic Factors Weight (chapter 4.3.5)

5.2.4 IF Application to the New Holland TG 285 Control Layout

The New Holland TG 285 was based on 8 different control types and a total of 54 controls. The most common control type, similar to the John Deere, Case IH and Buhler–Versatile, was the buttons with a total of 17 controls. Besides, its workstation had a total number of 15 rocker switches (Table 5.7).

Table 5.7 Different control types and total number of controls for the New Holland Cab

Control Types for the New Holland TG 285	**Number of Controls**
Steering Wheels	1
Buttons	17
Toggle Switches	10
Hand–Levers	2
Knobs	7
Rocker Switches	15
Rotary Switches	1
Multifunction Controls	1
Total number of controls	**54**

The ergonomic score for each factor was calculated and the 'Index of Functionality' value for the New Holland TG 285 was determined (Table 5.8). All the control types, except the buttons and knobs, resulted in a high ergonomic score. Moreover, all the ergonomic factors except the functional reach satisfied the given requirements. Consequently, the New Holland TG 285 cab was ranked fourth in terms of control's accessibility as it derived the fourth highest IF value among the modern tractor cabs.

Table 5.8 Application of Index of Functionality for the New Holland TG 285

Factors Considered for the New Holland TG 285	Ergonomic Score • Weight Factor*
Steering Wheel (Sw)	0.82 • 1
Buttons (Bp)	0.46 • 0.23
Toggle Switches (St)	0.75 • 0.12
Hand–Levers (L)	0.75 • 0.11
Knobs (Kb)	0.47 • 0.11
Rocker Switches (S)	0.79 • 0.38
Rotary Switches (Sr)	0.75 • 0.01
Multifunction Controls (Mc)	1 • 1
Placement of controls (Pc)	0.90 • 0.60
Suitability of controls (Sc)	0.94 • 0.48
Functional reach (Fr)	0.57 • 0.50
Control labelling (Lc)	0.63 • 0.42
IF	**0.72**

*Weight factor for the various control types (chapter 5.3.1)
Ergonomic Factors Weight (chapter 4.3.5)

5.2.5 IF Application to the Fendt 920 Vario Control Layout

The Fendt 920 Vario was based on 6 different control types and a total of 73 controls. The most common control type, similar to the previous tractor cabs, was the buttons with a total of 52 controls (Table 5.9).

Table 5.9 Different control types and total number of controls for the Fendt Cab

Control Types for the Fendt 920 Vario	Number of Controls
Steering Wheels	1
Buttons	52
Hand–Levers	4
Knobs	9
Rocker Switches	6
Multifunction Controls	1
Total number of controls	**73**

The ergonomic score for each factor was calculated and the 'Index of Functionality' value for the Fendt 920 Vario was determined (Table 5.10). All the control types, except the buttons, resulted in a high ergonomic score. On the other hand, two out of four ergonomic factors presented a low score. As a result, the Fendt 920 Vario cab was ranked fifth in terms of control's accessibility as it derived the fifth highest IF value among the modern tractor cabs.

Table 5.10 Application of Index of Functionality for the Fendt 920 Vario

Factors Considered for the Fendt 920 Vario	Ergonomic Score • Weight Factor*
Steering Wheel (Sw)	0.75 • 1
Buttons (Bp)	0.47 • 0.53
Hand–Levers (L)	0.81 • 0.17
Knobs (Kb)	0.77 • 0.13
Rocker Switches (S)	0.88 • 0.15
Multifunction Controls (Mc)	1 • 1
Placement of controls (Pc)	0.86 • 0.60
Suitability of controls (Sc)	0.94 • 0.48
Functional reach (Fr)	0.65 • 0.50
Control labelling (Lc)	0.61 • 0.42
IF	**0.70**

*Weight factor for the various control types (chapter 5.3.1)
Ergonomic Factors Weight (chapter 4.3.5)

5.2.6 IF Application to the Caterpillar Challenger MT665B Control Layout

The Caterpillar Challenger MT665B was based on 6 different control types and a total of 70 controls. This tractor was the only one that did not have a multifunction control compared to the other modern tractor cabs. The most common control type, similar to the previous tractor cabs, was the buttons with a total of 37 controls (Table 5.11).

Table 5.11 Different control types and total number of controls for the Caterpillar Cab

Control Types for the Caterpillar Challenger MT665B	Number of Controls
Steering Wheels	1
Buttons	37
Toggle Switches	4
Hand–Levers	7
Knobs	10
Rocker Switches	11
Total number of controls	**70**

The ergonomic score for each factor was calculated and the 'Index of Functionality' value for the Caterpillar Challenger MT665B was determined (Table 5.12). All the control types, except the buttons and toggle switches, resulted in the lowest ergonomic scores compared to the other modern tractor cabs. On the other hand, all the ergonomic factors except the control labelling demonstrated a remarkably high score, but the lack of multifunction control negatively influenced the overall assessment. The Caterpillar Challenger MT665B cab was ranked sixth in terms of control's accessibility as it derived the lowest IF value among the modern tractor cabs.

Table 5.12 Application of Index of Functionality for the Caterpillar Challenger MT665B

Factors Considered for the Caterpillar Challenger MT665B	**Ergonomic Score • Weight Factor***
Steering Wheel (Sw)	0.65 • 1
Buttons (Bp)	0.51 • 0.41
Toggle Switches (St)	0.50 • 0.03
Hand–Levers (L)	0.67 • 0.22
Knobs (Kb)	0.63 • 0.11
Rocker Switches (S)	0.72 • 0.22
Placement of controls (Pc)	0.90 • 0.60
Suitability of controls (Sc)	1 • 0.48
Functional reach (Fr)	0.91 • 0.50
Control labelling (Lc)	0.62 • 0.42
IF	**0.54**

*Weight factor for the various control types (chapter 5.3.1)
Ergonomic Factors Weight (chapter 4.3.5)

5.2.7 IF Application to the Fendt 275 S Control Layout

The Fendt 275 S was based on 6 different control types and a total of 17 controls. The most common control type was the hand–levers with a total of 7 controls (Table 5.13).

Table 5.13 Different control types and total number of controls for the Fendt Cab

Control Types for the Fendt 275 S	**Number of Controls**
Steering Wheels	1
Buttons	4
Toggle Switches	1
Hand–Levers	7
Knobs	3
Rocker Switches	1
Total number of controls	**17**

The ergonomic score for each factor was calculated and the 'Index of Functionality' value for the Fendt 275 S was determined (Table 5.14). All the control types, except the buttons and hand–levers, resulted in a moderate ergonomic score. Moreover, all the ergonomic factors except the control labelling which had a high score, demonstrated satisfying scores. Thus, the Fendt 275 S cab was ranked first in terms of control's accessibility as it derived the highest IF value among the old tractor cabs.

Table 5.14 Application of Index of Functionality for the Fendt 275 S

Factors Considered for the Fendt 275 S	Ergonomic Score • Weight Factor*
Steering Wheel (Sw)	0.40 • 1
Buttons (Bp)	0.75 • 0.15
Toggle Switches (St)	0 • 0.09
Hand–Levers (L)	0.60 • 0.50
Knobs (Kb)	0.55 • 0.18
Rocker Switches (S)	0.33 • 0.06
Placement of controls (Pc)	0.52 • 0.60
Suitability of controls (Sc)	0.58 • 0.48
Functional reach (Fr)	0.52 • 0.50
Control labelling (Lc)	0.82 • 0.48
IF	**0.32**

*Weight factor for the various control types (chapter 5.3.2)
Ergonomic Factors Weight (chapter 4.3.5)

5.2.8 IF Application to the Hurlimann H–478 Control Layout

The Hurlimann H–478 was based on 6 different control types and a total of 18 controls. The most common control type was the hand–levers with a total of 11 controls (Table 5.15).

Table 5.15 Different control types and total number of controls for the Hurlimann Cab

Control Types for the Hurlimann H–478	Number of Controls
Steering Wheels	1
Buttons	1
Toggle Switches	1
Hand–Levers	11
Knobs	2
Rocker Switches	2
Total number of controls	**18**

The ergonomic score for each factor was calculated and the 'Index of Functionality' value for the Hurlimann H–478 was determined (Table 5.16). All the control types, except the rocker switches, resulted in a low ergonomic score. In addition, all the ergonomic factors demonstrated low scores. Consequently, the Hurlimann H–478 cab was ranked second in terms of control's accessibility as it derived the second highest IF value among the old tractor cabs.

Table 5.16 Application of Index of Functionality for the Hurlimann H–478

Factors Considered for the Hurlimann H–478	Ergonomic Score • Weight Factor*
Steering Wheel (Sw)	0.40 • 1
Buttons (Bp)	0.50 • 0.02
Toggle Switches (St)	0 • 0.07
Hand–Levers (L)	0.42 • 0.55
Knobs (Kb)	0.50 • 0.25
Rocker Switches (S)	0.66 • 0.10
Placement of controls (Pc)	0.44 • 0.60
Suitability of controls (Sc)	0.50 • 0.48
Functional reach (Fr)	0.50 • 0.50
Control labelling (Lc)	0.37 • 0.42
IF	**0.24**

*Weight factor for the various control types (chapter 5.3.2)
Ergonomic Factors Weight (chapter 4.3.5)

5.2.9 IF Application to the Agrifull–Fiatagri 65 Control Layout

The Agrifull–Fiatagri 65 was based on 6 different control types and a total of 17 controls. The most common control type was the hand–levers with a total of 7 controls (Table 5.17).

Table 5.17 Different control types and total number of controls for the Agrifull–Fiatagri Cab

Control Types for the Agrifull–Fiatagri 65	Number of Controls
Steering Wheels	1
Buttons	4
Toggle Switches	1
Hand–Levers	7
Knobs	3
Rotary Switches	1
Total number of controls	**17**

The ergonomic score for each factor was calculated and the 'Index of Functionality' value for the Agrifull–Fiatagri 65 was determined (Table 5.18). All the control types, except the rocker switches, resulted in a low ergonomic score. In addition, all the ergonomic factors demonstrated low scores. Therefore, the Agrifull–Fiatagri 65 cab was ranked third in terms of control's accessibility as it derived the third highest IF value among the old tractor cabs.

Table 5.18 Application of Index of Functionality for the Agrifull–Fiatagri 65

Factors Considered for the Agrifull–Fiatagri 65	**Ergonomic Score • Weight Factor***
Steering Wheel (Sw)	0.22 • 1
Buttons (Bp)	0.25 • 0.16
Toggle Switches (St)	0.50 • 0.04
Hand–Levers (L)	0.28 • 0.62
Knobs (Kb)	0.11 • 0.12
Rotary Switches (S)	0.50 • 0.04
Placement of controls (Pc)	0.29 • 0.60
Suitability of controls (Sc)	0.58 • 0.48
Functional reach (Fr)	0.52 • 0.50
Control labelling (Lc)	0.70 • 0.42
IF	**0.20**

*Weight factor for the various control types (chapter 5.3.2)
Ergonomic Factors Weight (chapter 4.3.5)

5.2.10 IF Application to the Fiat 640 Control Layout

The Fiat 640 was based on 4 different control types and a total of 9 controls. The most common control type was the hand–levers with a total of 6 controls (Table 5.19).

Table 5.19 Different control types and total number of controls for the Fiat Cab

Control Types for the Fiat 640	**Number of Controls**
Steering Wheels	1
Buttons	1
Hand–Levers	6
Rotary Switches	1
Total number of controls	**9**

The ergonomic score for each factor was calculated and the 'Index of Functionality' value for the Fiat 640 was determined (Table 5.20). All the control types resulted in a remarkably low ergonomic score. Furthermore, all the ergonomic factors, except from the control labelling demonstrated very low scores. Thus, the Fiat

640 cab was ranked fourth in terms of control's accessibility as it derived the fourth highest IF value among the old tractor cabs.

Table 5.20 Application of Index of Functionality for the Fiat 640

Factors Considered for the Fiat 640	**Ergonomic Score • Weight Factor***
Steering Wheel (Sw)	0.22 • 1
Buttons (Bp)	0 • 0.06
Hand–Levers (L)	0.37 • 0.81
Rotary Switches (S)	0 • 0.12
Placement of controls (Pc)	0.22 • 0.60
Suitability of controls (Sc)	0.44 • 0.48
Functional reach (Fr)	0.44 • 0.50
Control labelling (Lc)	0.61 • 0.42
IF	**0.17**

*Weight factor for the various control types (chapter 5.3.2)
Ergonomic Factors Weight (chapter 4.3.5)

5.2.11 IF Application to the Steyr 650 Control Layout

The Steyr 650 was based on 3 different control types and a total of 9 controls. The most common control type was the hand–levers with a total of 6 controls (Table 5.21).

Table 5.21 Different control types and total number of controls for the Steyr Cab

Control Types for the Steyr 650	**Number of Controls**
Steering Wheels	1
Buttons	2
Hand–Levers	6
Total number of controls	**9**

The ergonomic score for each factor was calculated and the 'Index of Functionality' value for the Steyr 650 was determined (Table 5.22). All the control types and especially the hand–levers, resulted in a remarkably low ergonomic score.

Also, all the ergonomic factors, except from the control labelling, demonstrated very low scores. Hence, the Steyr 650 cab was ranked fifth in terms of control's accessibility as it derived the fifth highest IF value among the old tractor cabs.

Table 5.22 Application of Index of Functionality for the Steyr 650

Factors Considered for the Steyr 650	Ergonomic Score • Weight Factor*
Steering Wheel (Sw)	0.22 • 1
Buttons (Bp)	0.50 • 0.33
Hand–Levers (L)	0.16 • 0.66
Placement of controls (Pc)	0.22 • 0.60
Suitability of controls (Sc)	0.33 • 0.48
Functional reach (Fr)	0.44 • 0.50
Control labelling (Lc)	0.61 • 0.42
IF	**0.15**

*Weight factor for the various control types (chapter 5.3.2)
Ergonomic Factors Weight (chapter 4.3.5)

5.2.12 IF Application to the New Holland S 230 Control Layout

The New Holland S 230 was based on 4 different control types and a total of 12 controls. The most common control type was the hand–levers with a total of 7 controls (Table 5.23).

Table 5.23 Different control types and total number of controls for the New Holland Cab

Control Types for the New Holland S 230	Number of Controls
Steering Wheels	1
Buttons	1
Hand–Levers	7
Knobs	3
Total number of controls	**12**

The ergonomic score for each factor was calculated and the 'Index of Functionality' value for the New Holland S 230 was determined (Table 5.24). All the control types resulted in the lowest ergonomic scores compared to the other old tractor cabs. In addition, all the ergonomic factors demonstrated very low scores. Consequently, the New Holland S 230 cab was ranked sixth in terms of control's accessibility as it derived the lowest IF value among the old tractor cabs.

Table 5.24 Application of Index of Functionality for the New Holland S 230

Factors Considered for the New Holland S 230	**Ergonomic Score • Weight Factor***
Steering Wheel (Sw)	0.22 • 1
Buttons (Bp)	0 • 0.07
Hand–Levers (L)	0.24 • 0.71
Knobs (Kb)	0.22 • 0.21
Placement of controls (Pc)	0.16 • 0.60
Suitability of controls (Sc)	0.41 • 0.48
Functional reach (Fr)	0.41 • 0.50
Control labelling (Lc)	0.66 • 0.48
IF	**0.14**

*Weight factor for the various control types (chapter 5.3.2)
Ergonomic Factors Weight (chapter 4.3.5)

5.2.13 Determination of IF Average Values for the Modern and Old Tractors

In summary, the 'Index of Functionality' average values derived from the modern and from the old tractor control layouts were determined. The average value for the modern tractor layouts was found to be 0.71 whereas the average value for the old tractor layouts was found to be 0.20 (Table 5.25).

Table 5.25 IF average values for modern and old tractor control layouts

Modern Tractors	IF Values
John Deere 8220	0.83
Case IH MX 230	0.75
Buhler–Versatile 2210	0.73
New Holland TG 285	0.72
Fendt 920 Vario	0.70
Caterpillar Challenger MT665B	0.54
Average	**0.71**
Old Tractors	**IF Values**
Fendt 275 S	0.32
Hurlimann H–478	0.24
Agrifull–Fiatagri 65	0.20
Fiat 640	0.17
Steyr 650	0.15
New Holland S 230	0.14
Average	**0.20**

5.3 Determination of the Relative Frequency of Use for the Various Control Types

In this section the mathematical procedure for the determination of the relative frequency of use that was described in Chapter 4.2.2 will be applied to all the tractors.

First step. Initially, controls were categorized in five groups according to their general function based on the opinion of ten experienced agricultural tractor operators. A survey was conducted, in order to rank the categories of controls according to their frequency of use during a tillage operation. The results are presented in Chapter 4.2.1.

Second step. Six modern and six old tractor cabs were reviewed in terms of their total number of different types of controls present in each of them per control category.

In the first control category, one steering wheel was present in each modern tractor (Table 5.26).

Table 5.26 Total number of steering wheels in each modern tractor

Control Types	John Deere	Case IH	New Holland	Fendt	Caterpillar	Buhler–Versatile
Steering Wheel	1	1	1	1	1	1
Total number of controls*	**1**	**1**	**1**	**1**	**1**	**1**

*Rank in terms of frequency of use= 5

The second control category included the majority of control types (Table 5.27). The multifunction hand controls are not included in the total number of controls because their relative frequency of use will not be analyzed.

Table 5.27 Total number of controls related to the functioning of the implement in each modern tractor

Control Types	John Deere	Case IH	New Holland	Fendt	Caterpillar	Buhler–Versatile
Buttons	17	12	13	45	32	21
Rocker Switches	5	8	9	1	6	10
Toggle Switches	1	9	9	0	4	4
Knobs	4	3	2	4	8	3
Hand–Levers	0	0	0	1	3	2
Multifunction Hand Controls†	1	0	0	0	0	0
Total number of controls*	**27**	**32**	**33**	**51**	**53**	**40**

*Rank in terms of frequency of use= 4
†Multifunction Hand Controls are not included in the total number of controls

The third control category refers to controls related to the motion of tractors (Table 5.28). Similar to the second control category, the multifunction hand controls are not included in the total number of controls.

Table 5.28 Total number of controls related to the motion of the tractor in each modern tractor

Control Types	John Deere	Case IH	New Holland	Fendt	Caterpillar	Buhler–Versatile
Hand–Levers	1	1	1	2	2	0
Toggle Switches	1	0	0	0	0	0
Buttons	2	0	0	1	1	1
Rocker Switches	1	2	2	1	1	2
Multifunction Hand Controls†	0	1	1	1	0	1
Total number of controls*	**5**	**3**	**3**	**4**	**4**	**3**

*Rank in terms of frequency of use= 3

†Multifunction Hand Controls are not included in the total number of controls

The fourth control category includes the controls related to the internal environment of tractors (Table 5.29). Although this control category was ranked as less frequently used than the third, it contains more controls.

Table 5.29 Total number of controls related to the internal environment in each modern tractor

Control Types	John Deere	Case IH	New Holland	Fendt	Caterpillar	Buhler–Versatile
Knobs	3	3	3	4	2	2
Buttons	2	4	4	3	3	2
Rocker Switches	4	1	2	2	2	1
Toggle Switches	0	1	1	0	0	0
Hand–Levers	0	0	0	0	1	0
Total number of controls*	**9**	**9**	**10**	**9**	**8**	**5**

*Rank in terms of frequency of use= 2

The last control category includes the controls related to the external environment. This category was ranked as the least frequently used (Table 5.30).

Table 5.30 Total number of controls related to the external environment in each modern tractor

Control Types	John Deere	Case IH	New Holland	Fendt	Caterpillar	Buhler–Versatile
Knobs	3	1	2	1	0	3
Rocker Switches	2	3	2	2	2	1
Hand–Levers	1	1	1	1	1	1
Rotary Switches	0	1	1	0	0	0
Buttons	0	0	0	3	1	0
Total number of controls*	**6**	**6**	**6**	**7**	**4**	**5**

*Rank in terms of frequency of use= 1

The same procedure was followed for the old tractors. Based on the results, the types and the total number of controls present in each category were smaller compared to the modern tractors. In the first control category, one steering wheel was present in each old tractor (Table 5.31).

Table 5.31 Total number of steering wheels in each old tractor

Control Types	Agrifull–Fiatagri	Hurlimann	Fiat	Steyr	Fendt	New Holland
Steering Wheel	1	1	1	1	1	1
Total number of controls*	**1**	**1**	**1**	**1**	**1**	**1**

*Rank in terms of frequency of use= 5

Similar to the modern tractors, the second control category included the majority of control types (Table 5.32). The multifunction hand control did not exist in any of the old tractors.

Table 5.32 Total number of controls related to the functioning of the implement in each old tractor

Control Types	Agrifull–Fiatagri	Hurlimann	Fiat	Steyr	Fendt	New Holland
Buttons	4	0	0	2	1	1
Rocker Switches	0	2	0	0	1	0
Toggle Switches	1	0	0	0	0	0
Knobs	3	1	0	0	3	3
Hand–Levers	3	5	3	1	3	3
Rotary Switches	1	0	1	0	0	0
Total number of controls*	**12**	**8**	**4**	**3**	**8**	**7**

*Rank in terms of frequency of use= 4

The third control category refers to controls related to the motion of tractors (Table 5.33). Only two types of controls were used compared to the modern tractors where five control types were used.

Table 5.33 Total number of controls related to the motion of the tractor in each old tractor

Control Types	Agrifull–Fiatagri	Hurlimann	Fiat	Steyr	Fendt	New Holland
Hand–Levers	3	3	2	4	3	3
Toggle Switches	0	1	0	0	1	0
Total number of controls*	**3**	**4**	**2**	**4**	**4**	**3**

*Rank in terms of frequency of use= 3

The fourth control category includes the controls related to the internal environment of tractors (Table 5.34). Only one tractor had a control available for this kind of operation. Given this number, it can be summarized that the old tractor manufacturers did not pay attention to the conditions that existed in the internal environment of tractors.

Table 5.34 Total number of controls related to the internal environment in each old tractor

Control Types	Agrifull–Fiatagri	Hurlimann	Fiat	Steyr	Fendt	New Holland
Knobs	0	1	0	0	0	0
Total number of controls*	**0**	**1**	**0**	**0**	**0**	**0**

*Rank in terms of frequency of use= 2

The last control category includes the controls related to the external environment and it was ranked as the least frequently used (Table 5.35).

Table 5.35 Total number of controls related to the external environment in each old tractor

Control Types	Agrifull–Fiatagri	Hurlimann	Fiat	Steyr	Fendt	New Holland
Hand–Levers	1	3	1	1	1	1
Buttons	0	1	1	0	3	0
Total number of controls*	**1**	**4**	**2**	**1**	**4**	**1**

*Rank in terms of frequency of use= 1

Third step. After all the data described above was collected, the relative frequency of use for the different control types in each modern and old tractor cab per control category was determined as explained below.

Each control type present in each tractor cab was divided by the total number of controls in each tractor cab per control category (Table 5.36, 5.37, 5.38, 5.39, 5.40, 5.41, 5.42 and 5.43). The control category that referred to the steering wheel and the multifunction hand controls was not considered in the following calculations because the final model does not incorporate their relative frequency of use.

Table 5.36 Relative frequency of use for control types related to the functioning of the implement in each modern tractor

Control Types	John Deere	Case IH	New Holland	Fendt	Caterpillar	Buhler–Versatile
Buttons	(10)•17/27 =6.29	(10)•12/32 =3.75	(10)•13/33 =3.93	(10)•45/51 =8.82	(10)•32/53 =6.03	(10)•21/40 =5.25
Rocker Switches	(10)•5/27 =1.85	(10)•8/32 =2.5	(10)•9/33 =2.72	(10)•1/51 =0.19	(10)•6/53 =1.13	(10)•10/40 =2.5
Toggle Switches	(10)•1/27 =0.37	(10)•9/32 =2.81	(10)•9/33 =2.72	0	(10)•4/53 =0.75	(10)•4/40 =1
Knobs	(10)•4/27 =1.48	(10)•3/32 =0.93	(10)•2/33 =0.6	(10)•4/51 =0.78	(10)•8/53 =1.5	(10)•3/40 =0.75
Hand–Levers	0	0	0	(10)•1/51 =0.19	(10)•3/53 =0.56	(10)•2/40 =0.5
Multifunction Hand Controls†	1	0	0	0	0	0
Total number of controls*	**27**	**32**	**33**	**51**	**53**	**40**

*Rank in terms of frequency of use= 4
†Multifunction Hand Controls are not included in the total number of controls

Table 5.37 Relative frequency of use for control types related to the motion of the tractor in each modern tractor

Control Types	John Deere	Case IH	New Holland	Fendt	Caterpillar	Buhler–Versatile
Hand–Levers	(10)•1/5 =2	(10)•1/3 =3.33	(10)•1/3 =3.33	(10)•2/4 =5	(10)•2/4 =5	0
Toggle Switches	(10)•1/5 =2	0	0	0	0	0
Buttons	(10)•2/5 =4	0	0	(10)•1/4 =2.5	(10)•1/4 =2.5	(10)•1/3 =3.33
Rocker Switches	(10)•1/5 =2	(10)•2/3 =6.66	(10)•2/3 =6.66	(10)•1/4 =2.5	(10)•1/4 =2.5	(10)•2/3 =6.66
Multifunction Hand Controls†	0	1	1	1	0	1
Total number of controls*	**5**	**3**	**3**	**4**	**4**	**3**

*Rank in terms of frequency of use= 3
†Multifunction Hand Controls are not included in the total number of controls

Table 5.38 Relative frequency of use for control types related to the internal environment in each modern tractor

Control Types	John Deere	Case IH	New Holland	Fendt	Caterpillar	Buhler–Versatile
Knobs	(10)•3/9 =3.33	(10)•3/9 =3.33	(10)•3/10 =3	(10)•4/9 =4.44	(10)•2/8 =2.5	(10)•2/5 =4
Buttons	(10)•2/9 =2.22	(10)•4/9 =4.44	(10)•4/10 =4	(10)•3/9 =3.33	(10)•3/8 =3.75	(10)•2/5 =4
Rocker Switches	(10)•4/9 =4.44	(10)•1/9 =1.11	(10)•2/10 =2	(10)•2/9 =2.22	(10)•2/8 =2.5	(10)•1/5 =2
Toggle Switches	0	(10)•1/9 =1.11	(10)•1/10 =1	0	0	0
Hand–Levers	0	0	0	0	(10)•1/8 =1.25	0
Total number of controls*	**9**	**9**	**10**	**9**	**8**	**5**

*Rank in terms of frequency of use= 2

Table 5.39 Relative frequency of use for control types related to the external environment in each modern tractor

Control Types	John Deere	Case IH	New Holland	Fendt	Caterpillar	Buhler–Versatile
Knobs	(10)•3/6 =5	(10)•1/6 =1.66	(10)•2/6 =3.33	(10)•1/7 =1.42	0	(10)•3/5 =6
Rocker Switches	(10)•2/6 =3.33	(10)•3/6 =5	(10)•2/6 =3.33	(10)•2/7 =2.85	(10)•2/4 =5	(10)•1/5 =2
Hand–Levers	(10)•1/6 =1.66	(10)•1/6 =1.66	(10)•1/6 =1.66	(10)•1/7 =1.42	(10)•1/4 =2.5	(10)•1/5 =2
Rotary Switches	0	(10)•1/6 =1.66	(10)•1/6 =1.66	0	0	0
Buttons	0	0	0	(10)•3/7 =4.28	(10)•1/4 =2.5	0
Total number of controls*	**6**	**6**	**6**	**7**	**4**	**5**

*Rank in terms of frequency of use= 1

Table 5.40 Relative frequency of use for control types related to the functioning of the implement in each old tractor

Control Types	Agrifull-Fiatagri	Hurlimann	Fiat	Steyr	Fendt	New Holland
Buttons	(10)•4/12 =3.33	0	0	(10)•2/3 =6.66	(10)•1/8 =1.25	(10)•1/7 =1.42
Rocker Switches	0	(10)•2/8 =2.5	0	0	(10)•1/8 =1.25	0
Toggle Switches	(10)•1/12 =0.83	0	0	0	0	0
Knobs	(10)•3/12 =2.5	(10)•1/8 =1.25	0	0	(10)•3/8 =3.75	(10)•3/7 =4.28
Hand–Levers	(10)•3/12 =2.5	(10)•5/8 =6.25	(10)•3/4 =7.5	(10)•1/3 =3.33	(10)•3/8 =3.75	(10)•3/7 =4.28
Rotary Switches	(10)•1/12 =0.83	0	(10)•1/4 =2.5	0	0	0
Total number of controls*	**12**	**8**	**4**	**3**	**8**	**7**

*Rank in terms of frequency of use= 4

Table 5.41 Relative frequency of use for control types related to the motion of the tractor in each old tractor

Control Types	Agrifull–Fiatagri	Hurlimann	Fiat	Steyr	Fendt	New Holland
Hand–Levers	(10)•3/3 =10	(10)•3/4 =7.5	(10)•2/2 =10	(10)•4/4 =10	(10)•3/4 =7.5	(10)•3/3 =10
Toggle Switches	0	(10)•1/4 = 2.5	0	0	(10)•1/4 = 2.5	0
Total number of controls*	**3**	**4**	**2**	**4**	**4**	**3**

*Rank in terms of frequency of use= 3

Table 5.42 Relative frequency of use for control types related to the internal environment in each old tractor

Control Types	Agrifull–Fiatagri	Hurlimann	Fiat	Steyr	Fendt	New Holland
Knobs	0	(10)•1/1 =10	0	0	0	0
Total number of controls*	**0**	**1**	**0**	**0**	**0**	**0**

*Rank in terms of frequency of use= 2

Table 5.43 Relative frequency of use for control types related to the external environment in each old tractor

Control Types	Agrifull–Fiatagri	Hurlimann	Fiat	Steyr	Fendt	New Holland
Hand–Levers	(10)•1/1 =10	(10)•3/4 =7.5	(10)•1/2 =5	(10)•1/1 =10	(10)•1/4 =2.5	(10)•1/1 =10
Buttons	0	(10)•1/4 =2.5	(10)•1/2 =5	0	(10)•3/4 =7.5	0
Total number o controls*	**1**	**4**	**2**	**1**	**4**	**1**

*Rank in terms of frequency of use= 1

5.3.1 Calculation of the Relative Frequency of Use for the Different Control Types per Modern Tractor

The last step included the calculation of the relative frequency of use for the different control types per modern and old tractor.

All the data for each tractor regarding the relative frequency of use for their various control types (third step) was collected. For each tractor, the relative frequency of use determined for each control type per control category was multiplied by the rank of each control category in terms of its frequency of use (first step). Given that the same control type existed in more than one control categories, the sum of their product for all the control categories was calculated. The relevant calculations for the modern tractors are presented below:

1. John Deere 8220
   - Buttons: (6.29)•(4)+(4)•(3)+(2.22)•(2)= 41.6/99.87= 0.41
   - Rocker Switches: (1.85)•(4)+(2)•(3)+(4.44)•(2)+(3.33)•(1)= 25.61/99.87= 0.25
   - Toggle Switches: (0.37)•(4)+(2)•(3)= 7.48/99.87= 0.07
   - Knobs: (1.48)•(4)+(3.3)•(2)+(5)•(1)= 17.52/99.87= 0.17
   - Hand–Levers: (2)•(3)+(1.66)•(1)= + 7.66/99.87= 0.07

   99.87

2. Case IH MX 230
   - Buttons: (3.75)•(4)+(4.44)•(2)= 23.88/99.89= 0.23
   - Rocker Switches: (2.5)•(4)+(6.66)•(3)+(1.11)•(2)+(5)•(1)= 37.2/99.89= 0.37
   - Toggle Switches: (2.81)•(4)+(1.11)•(2)= 13.46/99.89= 0.13
   - Knobs: (0.93)•(4)+(3.33)•(2)+(1.66)•(1)= 12.04/99.89= 0.12
   - Hand–Levers: (3.33)•(3)+(1.66)•(1)= 11.65/99.89= 0.11
   - Rotary Switches: (1.66)•(1)= + 1.66/99.89= 0.01

   99.89

3. New Holland TG 285
   - Buttons: (3.93)•(4)+(4)•(2)= 23.72/99.83= 0.23
   - Rocker Switches: (2.72)•(4)+(6.66)•(3)+(2)•(2)+(3.33)•(1)= 38.19/99.83= 0.38
   - Toggle Switches: (2.72)•(4)+(1)•(2)= 12.88/99.83= 0.12
   - Knobs: (0.6)•(4)+(3)•(2)+(3.33)•(1)= 11.73/99.83= 0.11
   - Hand–Levers: (3.33)•(3)+(1.66)•(1)= 11.65/99.83= 0.11
   - Rotary Switches: (1.66)•(1)= + 1.66/99.83= 0.01

   99.83

4. Fendt 920 Vario
   - Buttons: (8.82)•(4)+(2.5)•(3)+(3.33)•(2)+(4.28)•(1)= 53.72/99.87= 0.53
   - Rocker Switches: (0.19)•(4)+(2.5)•(3)+(2.22)•(2)+(2.85)•(1)= 15.55/99.87= 0.15
   - Knobs: (0.78)•(4)+(4.44)•(2)+(1.42)•(1)= 13.42/99.87= 0.13
   - Hand–Levers: (0.19)•(4)+(5)•(3)+(1.42)•(1)= + 17.18/99.87= 0.17

   99.87

5. Caterpillar Challenger MT665B
   - Buttons: (6.03)•(4)+(2.5)•(3)+(3.75)•(2)+(2.5)•(1)= 41.62/99.88= 0.41
   - Rocker Switches: (1.13)•(4)+(2.5)•(3)+(2.5)•(2)+(5)•(1)= 22.02/99.88= 0.22
   - Toggle Switches: (0.75)•(4)= 3/99.88= 0.03
   - Knobs: (1.5)•(4)+(2.5)•(2)= 11/99.88= 0.11
   - Hand–Levers: (0.56)•(4)+(5)•(3)+(1.25)•(2)+(2.5)•(1)= + 22.24/99.88= 0.22

   99.88

6. Buhler–Versatile 2210
   - Buttons: (5.25)•(4)+(3.33)•(3)+(4)•(2)= 38.99/99.97= 0.39
   - Rocker Switches: (2.5)•(4)+(6.66)•(3)+(2)•(2)+(2)•(1)= 35.98/99.97= 0.35
   - Toggle Switches: (1)•(4)= 4/99.97= 0.04
   - Knobs: (0.75)•(4)+(4)•(2)+(6)•(1)= 17/99.97= 0.17
   - Hand–Levers: (0.5)•(4)+(2)•(1)= + 4/99.97= 0.04

     99.97

The final values regarding the frequency of use of the different control types for the modern tractors are presented in Table 5.44.

Table 5.44 Relative frequency of use of various control types for modern tractors

Control Types	John Deere	Case IH	New Holland	Fendt	Caterpillar	Buhler–Versatile
Toggle Switches	0.07	0.13	0.12	N/A	0.03	0.04
Buttons	0.41	0.23	0.23	0.53	0.41	0.39
Rocker Switches	0.25	0.37	0.38	0.15	0.22	0.35
Hand–Levers	0.07	0.11	0.11	0.17	0.22	0.04
Knobs	0.17	0.12	0.11	0.13	0.11	0.17
Rotary Switches	N/A	0.01	0.01	N/A	N/A	N/A

5.3.2 Calculation of the Relative Frequency of Use for the Different Control Types per Old Tractor

The same procedure was applied for the old tractors. The results are described below:

1. Agrifull–Fiatagri 65
   - Buttons: (3.33)•(4)= 13.32/79.96= 0.16
   - Rotary Switches: (0.83)•(4)= 3.32/79.96= 0.04
   - Toggle Switches: (0.83)•(4)= 3.32/79.96= 0.04
   - Knobs: (2.5)•(4)= 10/79.96= 0.12
   - Hand–Levers: (2.5)•(4)+(10)•(3)+(10)•(1)= + 50/79.96= 0.62

   79.96

2. Hurlimann H–478
   - Buttons: (2.5)•(1)= 2.5/100= 0.02
   - Rocker Switches: (2.5)•(4)= 10/100= 0.10
   - Toggle Switches: (2.5)•(3)= 7.5/100= 0.07
   - Knobs: (1.25)•(4)+(10)•(2)= 25/100= 0.25
   - Hand–Levers: (6.25)•(4)+(7.5)•(3)+(7.5)•(1)= + 55/100= 0.55

   100

3. Fiat 640
   - Buttons: (5)•(1)= 5/80= 0.06
   - Hand –Levers: (7.5)•(4)+(10)•(3)+(5)•(1)= 65/80= 0.81
   - Rotary Switches: (2.5)•(4)= + 10/80= 0.12

   80

4. Steyr 650
   - Buttons: (6.66)•(4)= 26.64/79.96= 0.33
   - Hand–Levers: (3.33)•(4)+(10)•(3)+(10)•(1)= + 53.32/79.96= 0.66

   79.96

5. Fendt 275 S
    - Buttons: (1.25)•(4)+(7.5)•(1)= 12.5/80= 0.15
    - Rocker Switches: (1.25)•(4)= 5/80= 0.06
    - Toggle Switches: (2.5)•(3)= 7.5/80= 0.09
    - Knobs: (3.75)•(4)= 15/80= 0.18
    - Hand–Levers: (3.75)•(4) + (7.5)•(3) + (2.5)•(1)= + 40/80= 0.50

    80

6. New Holland S 230
    - Buttons: (1.42)•(4)= 5.68/79.92= 0.07
    - Knobs: (4.28)•(4)= 17.12/79.92= 0.21
    - Hand–Levers: (4.28)•(4)+(10)•(3)+(10)•(1)= + 57.12/79.92= 0.71

    79.92

The final values regarding the frequency of use of the different control types for the old tractors are presented in Table 5.45.

Table 5.45 Relative frequency of use of various control types for old tractors

Control Types	Agrifull–Fiatagri	Hurlimann	Fiat	Steyr	Fendt	New Holland
Toggle Switches	0.04	0.07	N/A	N/A	0.09	N/A
Buttons	0.16	0.02	0.06	0.33	0.15	0.07
Rocker Switches	N/A	0.10	N/A	N/A	0.06	N/A
Hand–Levers	0.62	0.55	0.81	0.66	0.50	0.71
Knobs	0.12	0.25	N/A	N/A	0.18	0.21
Rotary Switches	0.04	N/A	0.12	N/A	N/A	N/A

6. DISCUSSION

In this chapter, the numerical index will be discussed in terms of any significant conclusions derived from its development procedure and from its final form. Also, the final average values of the model which resulted after its application to both tractor cab categories (i.e., modern and old) will be analyzed and compared. In this way, an overall assessment of the model will be conducted. The assessment will be related to the degree to which the model is capable of recognizing the ergonomic improvements that have been made by the manufacturers over the past several decades in tractor workstations. In addition, any limitations associated with the model will be discussed. Finally, there will be future study suggestions which may be beneficial to the improvement of the model.

6.1 The Index of Functionality as a Model for a Control Layout Assessment

A numerical index, referred to as the 'Index of Functionality' (IF), capable of comparing, on a mathematical basis, differing control arrangements in tractors was developed and validated. Basically, the development of the 'Index of Functionality' is based on two considerations.

The first consideration is the fact that the design dimensions of the different control types can affect their operation efficiency and, therefore, can influence the overall ergonomic acceptability of a control layout. It must be noted that the assessment of the control's operation efficiency is conducted by means of an experienced operator who should spend long hours working in a specific workstation in order to form a secure opinion regarding its ergonomic acceptability.

The second consideration is related to the effect of the general ergonomic issues of the system (i.e., the control panel) on the operator. In this way, the interaction between the operator and its most important design principles can be expressed. In this case, the operator is the direct determinant who influences the whole system operation (i.e., the workstation) and interacts with it, whereas in the first consideration the operator is the means through which an operation assessment of the various controls can be conducted.

In terms of analyzing the development procedure of the model it is obvious that the proportional principle is used. The evaluation of each control type is based on the proportion of controls that satisfy the relevant criteria. In this way, it is possible to determine the number of controls that meet the selected design dimensions being defined in relation to the total number of controls for a specific control type. Consequently, an overall evaluation for each control type can be conducted, in which the maximum value of the relevant sub–equation is 1 as the design dimensions considered are divided by their total number. In the final equation, this concept is applied to all the different types of controls that can be met plus the four ergonomic factors in which the relevant proportional values are determined. Consequently, the numerical index may take on any value ranging between 0 and +1 (e.g., 0, 0.1, 0.2, 0.3, . . .+1), with 1 being defined as the optimum value in terms of the functionality of an entire control layout.

In general, this definite range of possible values not only gives the opportunity to express the degree of functionality of a control panel in mathematical terms, but also gives the flexibility to compare two or more layouts and discover which of the controls are compatible with the expectations of the operator for easy, efficient, and convenient operation. As may be noted in the final equation, in each factor a different weight value is given. The factors can be categorized in three groups according to the given weight.

The first group (i.e., the first 6 factors) includes the various control types and for each one the relative frequency of use is its weight value. Specifically, the relative frequency of use for each control type is correlated directly with its most important design characteristics through the relevant sub–equation. Thus, the more that a specific type of control is used, the more its design characteristics will contribute to the determination of its final value. Theoretically, high correlation (i.e., final values close to 1), means that the overall design of a specific type of control is better.

In the second group (i.e., the four ergonomic factors), two weight values are given. The first weight value, which is equal to their average, is the same for the four factors and the second weight value, which is different for each factor, emphasizes their individually relevant importance in the tractor environment. Moreover, these values have been selected in order for the four ergonomic factors to be able to influence the final model value more than all the other factors (i.e., the various control types, the steering wheel, and the multifunction control).

Finally, a basic feature of this model is that it does not depend on the total number of controls present in a control layout. Thus, even if one workstation consists only of one or two control types it can still be assessed using the model without being at a disadvantage compared to the other workstations with more than two control types.

6.2 'Index of Functionality' (IF) versus 'Control Accessibility Index' *(Iα)*

A comparison between 'Control Accessibility Index' *(Iα)* (Banks and Boone 1981) and the method that is described in this thesis confirms the fact that there are some major differences and some minor similarities between them.

One similarity that both mathematical formulas present is that for the validation method, they do not use the criterion of operator performance, but both are based on different theoretical frameworks which do not include human performance measurements. A second similarity is that both models consider the factor of relative frequency of a control's use, although in each case, its determination is being conducted from a different point of view.

On the other hand, a major difference between the two models is that in the study by Banks and Boone, the reach envelopes were determined specifically for each operator who participated in the project, whereas in this study, consideration was given to the functional reach grip based on the 5^{th} male percentile. As a result, the current study can be applied to a broader range of possible operators. A second difference is that in the previous study, measurements were taken from both standing and seated positions while in this study measurements were taken considering that the operator is working in a seated position.

Finally, Banks and Boone report that the 'Control Accessibility Index' cannot be used as a stand–alone measure of accessibility, but as an adjunct measure within the context of the other related human factors standards. The current study intends to eliminate this 'cap' by considering in the same equation, not only the factors that were included in the previous model, but also the most important design and ergonomic factors related to operator–controls interaction.

6.3 Application of the Model to the Modern Tractor Workstations

The model was tested in six different modern tractor cabs having a manufacturing date from 2003 to 2005. The highest value derived from the model was 0.83 and the lowest was 0.54. The average value was found to be 0.71 out of 1. In general, results showed that the final value was ranged from 0.83 to 0.54 with most of the values to be uniformly spread between 0.83 and 0.70. Although the average value presented a high score, it could have been even higher due to the fact that the Caterpillar tractor cab resulted in a low score that negatively influenced the average value. The reason that the Caterpillar tractor demonstrated such a low score was the absence of a multifunction hand–control that, according to the numerical index, proved to be a very serious omission.

Regarding the design considerations on the different control types, modern tractors satisfied to a high degree the various requirements giving proportional values above 0.7. The only exception was the push buttons and in two cases (i.e., in Case IH MX 230 and in New Holland TG 285) the knobs, which constantly presented a low score below 0.51. Especially for the push buttons, none of the tractors resulted in a proportional value above 0.51 which means that immediate consideration should be given to their design if manufacturers desire to improve their operation efficiency.

Concerning the ergonomic factors, modern tractors demonstrated reasonable results. The first two factors (i.e., the placement and suitability of controls) presented high values above 0.85. The values for the last two factors were a bit lower than the first two and they ranged between 0.57 and 0.98. The conclusion that can be derived by examining the results of the ergonomic factors is that designers should be more aware of the control labelling issues if they want to achieve not only easier control readability but also an improved overall image. The impression that a control layout can make on an operator in terms of control labelling should meet or exceed his perception of what is appropriate for the specific situation. The use of labels that appear to be poorly placed and designed conveys a sense that the job being performed and the workspace are not important.

In general, most of the modern tractors were compatible with the requirements of the model and each proportion usually resulted in a value above 0.65 out of 1.

6.4 Application of the Model to the Old Tractor Workstations

The model was tested in six different old tractor cabs having a manufacturing date from 1975 to 1981. The highest value derived from the model was 0.32 and the lowest was 0.14. The average value was found to be 0.20 out of 1. In general, results showed that the final value ranged from 0.32 to 0.14 with most of the values to be uniformly spread between 0.24 and 0.14. An interesting point was that although the Fendt tractor had almost the same manufacturing date as the other old tractors, it demonstrated an unusual high final value compared to the other tractors.

Regarding the design considerations on the different control types, old tractors except the Fendt, did not satisfy any of the various requirements giving proportional values below 0.4. Especially for the hand–levers which were the most used control type, none of the tractors resulted in a proportional value above 0.6.

Concerning the ergonomic factors, old tractors demonstrated disappointing results. Specifically, all the factors except the control labelling presented remarkably low values below 0.58. The values for the control labelling were higher and they were ranged between 0.82 and 0.37. The conclusion that can be derived by examining the results of the ergonomic factors is that designers were not aware of ergonomic aspects of the controls at this time (i.e., from the 1970s to the early 1980s).

In general, the majority of the old tractors were not in accordance with the requirements that have been set by the model and each proportion usually resulted in a value below 0.5 out of 1.

6.5 Overall Assessment of the Model

Intuitively, we knew that a number of ergonomic improvements have been made by tractor manufacturers on the control layout over the past several decades. The 'Index of Functionality' attempted to recognize these improvements and express them in a mathematical way. A comparison between the modern and old tractor average values derived from the model confirmed our intuition. Specifically, their difference was found to be 0.51 out of the theoretical value of 1. As a result, it is obvious that this value represents the current ergonomic gap that exists between the control layouts of the modern and old tractors.

Regarding the modern tractors, the results indicated the sectors that require further consideration from the manufacturers in order to be even more compatible from the ergonomic perspective with the user. Concerning the old tractors, the results showed that the model has effectively recognized their weakness to offer an efficient and convenient operation environment for the driver due to their serious omissions in ergonomic design considerations.

Concluding, the 'Index of Functionality' was proved to be an effective 'tool' which clearly recognized the latest ergonomic improvements in tractor workstations.

6.6 Limitations of the Model

There are considerable limits imposed by the use of IF. First, in order to apply the numerical index there must be at least one control in each proportion considered which will satisfy the given requirements. As a result, the relative sub–equations referred to the various control types will present a value which can be bigger than 0 and equal or less than 1 (i.e., $0 <$ value from the sub–equations ≤ 1).

Second, the procedure that has been followed for the determination of the relative frequency of use for the various control types does not intend to use the criterion of operator performance, but it is based on a theoretical framework. Any attempt to calculate their relative frequency of use using the criterion of operator performance should be carefully applied. The observation time, the operation being conducted (i.e., the workload), the level of the operator experience, the tractor type, and the tractor age are some factors that should be considered.

Third, the different control types that are included in the numerical index have been added after reviewing many modern tractor cabs. In the future, attention must be given to any new additions of control types that will be used.

Fourth, this model was developed to be exclusively applied in agricultural tractors. Any application in agricultural vehicles other than tractors must be conducted with extreme caution due to some restrictions that may apply (i.e., use of different control types, different expectations from the operator in terms of his or her workload, and kind of the operation).

6.7 The Fundamental Elements of the Model

After analyzing the 'Index of Functionality', it can be concluded that it consists of the sum of the factors (i.e., Design Considerations on Control Types + Ergonomic Factors + Steering Wheel + Multi-function Control). Based on this fact, a decision had to be made regarding the weight values of the four ergonomic factors. A number of calculations demonstrated that by giving them different weight values, which were in accordance with the survey results, the overall weight distribution of the four factors in the final model value was different.

The final decision was that the model value should be influenced, in terms of weight distribution, as follows: first from the ergonomic factors, second from the multifunction control, third from the different control types, and fourth from the steering wheel. As a result, the mentioned weight values for the four ergonomic factors were given (Chapter 4.3.5).

The reason for setting up this rank is based on the fact that the four ergonomic factors is the most important consideration to provide a workstation based on the 'user–centered' design concept. For example, it is useless for a tractor operator to have the most basic control (i.e., the multifunction control) outside his functional reach or be located on the left hand–side. Providing the appropriate conditions for the interaction between the system and the user by following the human factors guidelines is the first step.

The second most important step is based on the design of the various control types. However, the fact that in modern tractors the multifunction control is the control that through it, all the critical operations can be conducted, led us to rank it as the second most important. Even if its design characteristics are not in accordance with the recommended design dimensions, the multifunction control still remains the most crucial control for the tractor operation. By example, assume a push button with a 50 mm diameter is located on a multifunction control. This dimension is not in accordance with the recommended design guidelines. Nevertheless, the operator will be still able to make the necessary adjustments through this button even if its diameter is 25 mm bigger than the maximum acceptable value.

The last important step is based on the steering wheel. This control was selected to influence the final model value less than the other factors contrary to the basic operation principle. This principle mentions that in tractors the driver's left hand must be available for steering at all times. For example, assuming a steering wheel that has a rim thickness outside the recommended design guidelines (e.g., 50 mm). This fact cannot negatively influence the accessibility of the steering wheel and as a result the driver operation. In addition, a better understanding of the driving process, especially in modern tractors, can answer any questions arising regarding the role of the steering wheel.

Nowadays, it is generally accepted that there are new standards concerning the interaction between the driver and the level of his 'active participation' while operating a tractor. A representative example is the steering wheel. According to the latest technology improvements (e.g., the use of auto–guide guidance systems), the driver is not required to devote so much attention to steering due to the fact that most of the major functions can be executed automatically. Generally, this means that the introduction of new technology has changed the traditional role of the 'active driver' to the 'passive driver' by means of supervising the operation.

6.8 Further Steps to Improve the Model

A number of interesting research topics derived from this study are targeted at improving the model's applicability. Specifically, further study should be conducted to discover the degree to which the various environmental factors in the cab (i.e., cab temperature, cab moisture, and cab brightness) influence the accessibility of the controls and, therefore, the operation efficiency. In addition, the interaction between some basic operation characteristics (i.e., workload/hour and total operation time) and the accessibility of the various controls should be examined. Does the kind of task that is executed affect the operator in terms of his ability to access the controls during long working hours? If there is a strong correlation found, it may be possible to establish a specific model according to the given operation conditions.

Another study area is the effect of the seat characteristics in the efficient operation of the controls. Any new additions to the model, that indicate the acceptable dimensions of the most basic seat design characteristics of the tractors would be an opportunity to relate the accessibility of controls with the sitting position of the operator.

Also an important addition to the model would be the consideration of new control types in terms of their design characteristics that will potentially be used in future tractor workstations.

A study regarding the determination of the relative frequency of use based on the criterion of operator performance during real–time operation would be a very interesting addition. Consequently, the operator would be considered as an 'active' determinant. This is in comparison to the current model in which the operator is a 'passive' determinant.

Moreover, future work should include the determination of the percentage of operators, in terms of their age and anthropometric dimensions, in which this model can be ideally applicable as well as the possible application of the model in extreme cases where the anthropometric dimensions of the operator are smaller than the 5^{th} or bigger than the 95^{th} percentile.

Furthermore, work should also be done in order to examine the applicability of the model to other agricultural vehicles.

Finally, high research interest presents the potential application of the model in different drafts of the same control layout of a tractor to discover which one is the most accessible for the operator. If the model recognizes any ergonomic improvements among different drafts, then designers would be able to consider the ergonomic point of view in the early stages of the design process.

7. CONCLUSIONS

The following conclusions were obtained from this work:

1. A numerical index, referred to as the 'Index of Functionality' (IF), capable of comparing, on a mathematical basis, differing control layouts in terms of their degree of functionality, was developed. The procedure used for its development consisted of the determination of twelve factors which incorporated into one or more proportional values. The numerical index may take on any value ranged between 0 and +1, e.g. 0, 0.1, 0.2, 0.3, . . . +1, with +1 being defined as an optimum value in terms of the functionality of an entire control panel.
2. The 'Index of Functionality' was successfully applied to a total number of six old and six modern tractors control layouts. Results showed that the average value for the modern tractors was 0.71 out of 1 and for the old tractors was 0.20 out of 1. Consequently, the difference between them was found to be 0.51 out of the theoretical value of 1. Based on the observed value it can be confirmed that the 'Index of Functionality' effectively recognized the improvements that have occurred in the ergonomic design of tractor workstations over the past 20 years.

In addition, through the development of the model (i.e., first objective) the following secondary conclusions were derived:

1. The evaluation of each control type was based on the proportional values that were used to establish an ergonomic score for each of them. In this way, it was possible to determine the number of controls that met the selected design dimensions defined in relation to the total number of

controls for a specific control type. A weight value was given in each control type equal to their relative frequency of use.

2. Four ergonomic factors were considered that are of a high importance in describing control layout functionality in tractors. In each factor, a different weight value was given in such a way to emphasize their relevant importance in the tractor environment. Moreover, these weight values have been selected in order for the four ergonomic factors to be able to influence the final model value more than the other factors (i.e., the design considerations on various control types, the steering wheel and the multifunction control).

Based on the results from the model validation (i.e., second objective) the following secondary conclusions were obtained concerning the design status of modern and old tractor workstations:

1. Regarding the design considerations on the different control types, modern tractors satisfied to a high degree the various requirements giving proportional values above 0.7 out of 1, with the push buttons to be the only exception. In addition, they demonstrated reasonable results for the ergonomic considerations. In general, most of the modern tractors were compatible with the requirements of the model and each proportion usually resulted in a value above 0.65 out of 1.
2. Regarding the design considerations on the different control types, old tractors except the Fendt 275 S, did not satisfy any of the various requirements giving proportional values below 0.4. In addition, they demonstrated disappointing results for the ergonomic factors having remarkably low values below 0.58. In general, the majority of the old

tractors were not in accordance with the requirements that have been set by the model and each proportion usually resulted in a value below 0.5 out of 1.

Concluding, it is important to consider that there is no perfect control layout or universal definition of control functionality. Thus, no matter how good a control layout may be, there will always be chances for improvement and criticism. Aspects like control arrangement and control functionality are hard to measure meaningfully and are subject to personal preference and the kind of work rather than the objective standards.

REFERENCES

American Society of Agricultural and Biological Engineers. 2000. ASABE S304.7, Graphical Symbols for Operator Controls and Displays on Agricultural Equipment. St. Joseph, MI: ASABE.

American Society of Agricultural and Biological Engineers. 2004. ASABE S335.4, Operator Controls on Agricultural Equipment. St. Joseph, MI: ASABE.

Bailey, R.W. 1989. *Human Performance Engineering,* 2nd edition. Englewood Cliffs, NJ: Prentice Hall.

Banks, W.W. and M.P. Boone. 1981. A method for quantifying control accessibility. *Human Factors* 23(3): 299–303.

Burgess, J.H. 1986. *Designing for Humans: The Human Factor in Engineering.* Princeton, NJ: Petrocelli Books.

Chaffin, D.B. 1987. Biomechanical aspects of workplace design. In *Handbook of Human Factors,* ed. G. Salvendy. New York, NY: John Wiley and Sons.

Chapanis, A., R. G. Wendell, C.T. Morgan. 1949. *Applied Experimental Psychology: Human Factors in Engineering Design.* New York, NY: John Wiley and Sons.

Clark, T.S. and Corlett, E.N. 1995. *The Ergonomics of Workspace and Machines: A Design Manual*, 2nd edition. London: Taylor and Francis.

Department of Defense. 1976. Aircrew Station Geometry for Military Aircraft, *MIL-STD-1333A*. Washington, DC: Department of Defense.

Department of Defense. 1999. Human Engineering Design Criteria Standard, *MIL–STD–1472F*. Washington, DC: Department of Defense.

Department of Transportation. 1996. *Human Factors Design Guide.* URL: http://www.hf.faa.gov/docs/508/docs/hfdg.pdf (2005/04/12).

Directory and Yearbook of Human Factors and Ergonomics. 2005. Santa Monica, CA: Human Factors and Ergonomics Society.

Dumas, J. S. 1993. *A Practical Guide to Usability Testing*. Norwood, NJ: Ablex Publishing.

Dupuis, H. 1955. The relationship between maximum pulling force and location of control handle. In *Human Factors in Engineering and Design*, 7th edition, ed. M.S. Sanders. New York, NY: McGraw–Hill.

Dupuis, H. 1957. Farm tractor operation and human stresses. In *proceedings ASABE Conference*, 35–42. Chicago, IL. December 15–18.

Ely, J.H., R.M. Thomson and J. Orlansky. 1956. Layout of workplaces: Human engineering guide to equipment design. Report 56–171. Columbus, OH: Wright–Patterson Air Force Base–Wright Air Development Center.

Gamst, F.C. 1975. Human factors analysis of diesel electric locomotive cab. *Human Factors* 17 (2): 149–156.

Grandjean, E. 1988. *Fitting the Task to the Man*, 4th Edition. New York, NY: Taylor and Francis.

Helander, M. 1988. *Handbook of Human–Computer Interaction*. New York, NY: Elsevier/North Holland.

Howe, J.G., F. Chambers and L.K. Sullivan. 1992. Assessment of vehicle interior dimensions and lap/shoulder belt fit. Washington, DC: National Highway Traffic Safety Administration.

International Organization for Standardization. 1998. ISO 3767–1, Tractors, Machinery for Agriculture and Forestry, Powered Lawn and Garden Equipment–Symbols for Operator Controls and Other Displays—Part 1: Common Symbols. Geneva: ISO.

Ivergard, T. 1989. *Handbook of Control Room Design and Ergonomics*. New York, NY: Taylor and Francis.

Konz, S. 1990. *Work Design: Industrial Ergonomics*. Phoenix, AZ: Horizons Inc.

Laux, L.F. 1991. *Locating Vehicle Controls and Displays: Effects of Expectancy and Age*. Washington, DC: AAA Foundation for Traffic Safety.

McFarland, R. A. 1946. *Human Factors in Air Transport Design*. New York, NY: McGraw–Hill.

McFarland, R. A., A. Damon, H. W. Stoudt, A. L. Mosley, J. W. Dunlap and W. A. Hall. 1953. *Human Body Size and Capabilities in the Design and Operation of Vehicular Equipment*. Boston, MA: Harvard School of Public Health.

Miller, D.P. and A.D. Swain. 1988. Human error and human reliability. In *Handbook of Human–Computer Interaction*, ed. M. Helander, New York, NY: Elsevier/North Holland.

Moussa–Hamouda, E., and R. Mourant. 1981. Vehicle fingertip reach controls–human factors recommendations. *Ergonomics* 12: 66–70.

Nielsen, J. 1993. *Usability Engineering*. Boston, MA: AP Professional.

National Aeronautics and Space Administration. 1978. *Anthropometric Source Book*, Vol. I and II, Reference number 1024. Washington, DC: National Aeronautics and Space Administration.

National Aeronautics and Space Administration. 1995. Man–Systems Integration Standards, STD–3000. Houston, TX: National Aeronautics and Space Administration.

National Safety Council. 1978. *Accident Facts*. Chicago, IL: National Safety Council.

Pheasant, S. 1986. *Bodyspace: Anthropometry, Ergonomics and Design*. London: Taylor and Francis.

Purcell, W. F. H. 1980. *The Human Factor in Farm and Industrial Equipment Design*. St. Joseph, MI: ASABE.

Road Freight Transport Industry. 2005. URL: http://www.tsitc.asn.au/Documents/OcHealth&Safety/05%20Choosing%20a%20seat.pdf (2005/09/16).

Rogers, S.P. and L.D. Myers. 1993. Development of an intelligent system to aid in avionics display design. In *proceedings 12th AIAA/IEEE Digital Avionics System Conference*, 160–166. Fort Worth, TX. October 25–28.

Salvendy, G. 1987. *Handbook of Human Factors*. New York, NY: John Wiley and Sons.

Sanders, M.S. and E.J. McCormick. 1993. *Human Factors in Engineering and Design*, 7th edition. New York, NY: McGraw–Hill.

Seminara, J.L., W.R. Gonzalez and S.O. Parsons. 1977. Human factor review of nuclear power plant control room design. Report NP–309. Palo Alto, CA: Electric Power Research Institute.

Shneiderman, B. 1992. *Designing the User Interface: Strategies for Effective Human–Computer Interaction*, 2nd edition. Reading, MA: Addison–Wesley.

Smith, S. and J. Mosier. 1986. *Guidelines for Designing User Interface Software*. Bedford, MA: MITRE Corporation.

Tullis, T.S. 1988. Screen design. In *Handbook of Human–Computer Interaction*, ed. M. Helander. New York, NY: Elsevier/North Holland.

US Army Material Command. 1976. *Theory and Practice: Engineering Design Handbook–Maintainability Guide for Design*. Headquarters, US: Army Material Command.

Valtra Tractors. 2005. URL: http://www.valtra.com (2005/04/25).

Van Cott, H.P. and R.G. Kinkade. 1972. *Human Engineering Guide to Equipment Design*. Washington DC: Government Printing Office.

Weimer, J. 1993. *Handbook of Ergonomic and Human Factors Tables*. Englewood Cliffs, NJ: Prentice Hall.

Wierwille, W. 1984. The design and location of controls: A brief review and an introduction to new problems. In *Ergonomic Data for Equipment Design, ed.* H. Schmidtke. New York, NY: Plenum Press.

Wikipedia. 2005. URL: http://en.wikipedia.org/wiki/Left-handed. (2005/10/11).

APPENDICES

Appendix A

Calculation Sheets for the IF

Index of Functionality for the John Deere 8220

1. Toggle Switches (St)

- St1 = Proportion of Toggle Switches having an Arm Length between 12 and 50 mm (0.5–2 in): **St1 = 2/2= 1.**
- St2 = Proportion of Toggle Switches having a minimum Separation of 50 mm (2 in): **St2 = 1/2= 0.5.**
- F_{St} = Relative frequency of use for toggle switches: **F_{St} = 0.07.**

$$FSt \cdot St = FSt \cdot (St1 + St2)/2$$

2. Rocker Switches (S)

- S1 = Proportion of Rocker Switches having a minimum Width of 6 mm (0.25 in): **S1 = 12/12= 1.**
- S2 = Proportion of Rocker Switches having a minimum Length of 12 mm (0.5 in): **S2 = 11/12= 0.91.**
- S3 = Proportion of Rocker Switches having a minimum Separation of 19 mm (0.75 in): **S3 = 11/12= 0.91.**
- F_S = Relative frequency of use for rocker switches: **F_S = 0.25.**

$$Fs \cdot S=Fs \cdot (S1+S2+S3)/3$$

3. Knobs (Kb)

- Kb1 = Proportion of Knobs having a Height between 12 and 25 mm (0.5–1 in): **Kb1 = 10/10= 1.**
- Kb2 = Proportion of Knobs having a Diameter between 12 and 100 mm (0.5–4 in): **Kb2 = 10/10= 1.**
- Kb3 = Proportion of Knobs having a minimum Separation of 50 mm (2 in): **Kb3 = 4/10= 0.4.**
- F_{Kb} = Relative frequency of use for knobs: **F_{Kb} = 0.17.**

$$FKb \cdot Kb = FKb \cdot (Kb1 + Kb2 + Kb3)/3$$

4. Push Buttons (Bp)

- Bp1 = Proportion of Push Buttons having a Diameter between 12 and 25 mm (0.5–1 in): **Bp1 = 19/21= 0.9.**
- Bp2 = Proportion of Push Buttons having a minimum Separation of 50 mm (2 in): **Bp2 = 2/21= 0.09.**
- FBp = Relative frequency of use for push buttons: **FBp = 0.41.**

$$FBp \cdot Bp = FBp \cdot (Bp1 + Bp2)/2$$

5. Hand–Levers (L)

- L1 = Proportion of Hand–Levers that require a maximum Activation Force of 16 kg (35 lbf): **L1 = 2/2= 1.**
- L2 = Proportion of Hand–Levers having a maximum Displacement of 355 mm (14 in): **L2 = 2/2= 1.**
- L3 = Proportion of Hand–Levers having a minimum Separation of 100 mm (4 in): **L3 = 0/2= 0.**
- L4 = Proportion of Hand–Levers that are located between 570 to 660 mm (22.4 to 26 in) covering a 90° envelope in front of the Seat Reference Point: **L4 = 1/2= 0.5.**
- FL = Relative frequency of use for hand–levers: **FL = 0.07.**

$$FL \cdot L = FL \cdot (L1 + L2 + L3 + L4)/4$$

6. Steering Wheel (Sw)

- Sw1 = If the Diameter is between 400 and 510 mm (15.7–20 in) then Sw1 = 1.
  - **Sw1 = 1.**
- Sw2 = If the Rim Thickness is between 19 and 32 mm (0.75–1.25 in) then Sw2 = 1.
  - **Sw2 = 1.**
- Sw3 = Proportion of any Hand–Levers located on steering wheel column that have a maximum vertical distance from the steering wheel to their top of 63.5 mm (2.5 in): **Sw3 = 1/4= 0.25.**

- Sw4 = If the Angle to the horizontal plane is between 40 and 60 degrees then Sw4 = 1.
    - **Sw4 = 1.**

$$Sw = (Sw1 + Sw2 + Sw3 + Sw4)/4$$

7. Multifunction Hand Controls (Mc)

- If a Multifunction Hand Control, which combines at least two control types and satisfies all the requirements, is presented, then the Multifunction Hand Control Ideal value will be equal to 1 = Mc.
    - **Mc = 1.**

8. Control Labeling (Lc)

- Lc1 = Proportion of controls having an associated title e.g. a label (*above the controls*) or indication *(e.g. icon, symbol)*: **Lc1 = 46/49= 0.93.**
- Lc2 = Colour – coding: If no more than four colours are used that are well spaced in chroma then Lc2 = 1.

    Lc2 = Colour – coding: Number of colours that are used: *4*, therefore **Lc2 = 1.**

$$Lc = (Lc1 + Lc2)/2$$

9. Functional Reach (Fr)

- Proportion of controls present within a radius of 750 mm (29.5 in) covering a 180° envelope in front of the operator: **Fr = 43/49= 0.87.**

10. Suitability of Controls (Sc)

- Proportion of controls where mode of action is appropriate to function: **Sc = 46/49= 0.93.**

11. Placement of Controls (Pc)

- Proportion of controls present on the right hand side of the operator: **Pc = 46/49= 0.93.**

Calculations

$$I_F = \frac{(F_{Sr}\cdot Sr)+(F_{St}\cdot St)+(F_S\cdot S)+(F_{Kb}\cdot Kb)+(F_{Bp}\cdot Bp)+(F_L\cdot L)+(Ea)\cdot[(0.6\cdot Pc)+(0.48\cdot Sc)+(0.5\cdot Fr)+(0.42\cdot Lc)]+Sw+Mc}{\sum^{n} F+4}$$

- Toggle Switches = St = (St1 + St2)/2
  - F_{St} = relative frequency of use for toggle switches = 0.07.
  - St = (1+0.5)/2= 1.5/2= 0.75.
- Rocker Switches = S = (S1 + S2 + S3)/3
  - F_S = relative frequency of use for rocker switches = 0.25.
  - S = (1+0.91+0.91)/3= 2.82/3= 0.94.
- Knobs = Kb = (Kb1 + Kb2 + Kb3)/3
  - F_{Kb} = relative frequency of use for knobs = 0.17.
  - Kb= (1+1+0.4)/3= 2.4/3= 0.80.
- Push Buttons = Bp = (Bp1 + Bp2)/2
  - F_{Bp} = relative frequency of use for push buttons = 0.41.
  - Bp= (0.9+0.09)/2= 0.99/2= 0.49.
- Hand–Levers = L = (L1 + L2 + L3 + L4)/4
  - F_L = relative frequency of use for hand–levers = 0.07.
  - L = (1+1+0+0.5)/4= 2.5/4= 0.62.
- Steering Wheel = Sw = (Sw1 + Sw2 + Sw3 + Sw4)/4
  - Sw = (1+1+0.25+1)/4= 3.25/4= 0.81.
- Presence of Multifunction Hand Controls = Mc
  - Mc = 1.
- Placement of Controls = Pc
  - Pc = 0.93.
- Suitability of Controls = Sc
  - Sc = 0.93.
- Functional Reach = Fr
  - Fr = 0.87.
- Control Labeling = Lc = (Lc1 + Lc2)/2
  - Lc = (0.93+1)/2= 1.93/2= 0.96.

- Ea = Ergonomic factors average = [(Pc+Sc+Fr+Lc)/4] = 0.92.
- n =5= Number of control types (maximum value n = 6, excluding Sw and Mc)

$$I_F = \frac{(0.07\cdot0.75)+(0.25\cdot0.94)+(0.17\cdot0.8)+(0.41\cdot0.49)+(0.07\cdot0.62)+(0.92)\cdot[(0.6\cdot0.93)+(0.48\cdot0.93)+(0.5\cdot0.87)+(0.42\cdot0.96)]+(0.81)+(1)}{(0.07+0.25+0.17+0.41+0.07)+(4)}$$

$$I_F = \frac{(0.05)+(0.23)+(0.13)+(0.20)+(0.04)+(0.92)\cdot[1.82]+(0.81)+(1)}{(0.97)+(4)}$$

$$I_F = \frac{(0.65)+(0.92)\cdot[1.82]+(0.81)+(1)}{(4.97)}$$

$$\mathbf{I_F = 0.83.}$$

Index of Functionality for the Case IH MX 230

1. Rotary Switches (Sr)

- Sr1 = Proportion of Rotary Switches having a Length between 25 and 76 mm (1–4 in): **Sr1 = 1/1= 1.**
- Sr2 = Proportion of Rotary Switches having a Width up to 25 mm (1 in): **Sr2 = 1/1= 1.**
- Sr3 = Proportion of Rotary Switches having a Height between 12 and 75 mm (0.5–3 in): **Sr3 = 0/1= 0.**
- Sr4 = Proportion of Rotary Switches having a minimum Separation of 25 mm (1 in): **Sr4 = 1/1= 1.**
- F_{Sr} = Relative frequency of use for rotary switches: $\mathbf{F_{Sr} = 0.01}$.

$$FSr \cdot Sr = FSr \cdot (Sr1 + Sr2 + Sr3 + Sr4)/4$$

2. Toggle Switches (St)

- St1 = Proportion of Toggle Switches having an Arm Length between 12 and 50 mm (0.5–2 in): **St1 = 9/10= 0.9.**
- St2 = Proportion of Toggle Switches having a minimum Separation of 50 mm (2 in): **St2 = 6/10= 0.6.**
- F_{St} = Relative frequency of use for toggle switches: $\mathbf{F_{St} = 0.13}$.

$$FSt \cdot St = FSt \cdot (St1 + St2)/2$$

3. Rocker Switches (S)

- S1 = Proportion of Rocker Switches having a minimum Width of 6 mm (0.25 in): **S1 = 14/14= 1.**
- S2 = Proportion of Rocker Switches having a minimum Length of 12 mm (0.5 in): **S2 = 13/14= 0.92.**
- S3 = Proportion of Rocker Switches having a minimum Separation of 19 mm (0.75 in): **S3 = 7/14= 0.5.**
- Fs = Relative frequency of use for rocker switches: **Fs = 0.37.**

$$Fs \cdot S = Fs \cdot (S1+S2+S3)/3$$

4. Knobs (Kb)

- Kb1 = Proportion of Knobs having a Height between 12 and 25 mm (0.5–1 in): **Kb1 = 3/7= 0.42.**
- Kb2 = Proportion of Knobs having a Diameter between 12 and 100 mm (0.5–4 in): **Kb2 = 7/7= 1.**
- Kb3 = Proportion of Knobs having a minimum Separation of 50 mm (2 in): **Kb3=1/7=0.14.**
- FKb = Relative frequency of use for knobs: **FKb = 0.12.**

$$FKb \cdot Kb = FKb \cdot (Kb1 + Kb2 + Kb3)/3$$

5. Push Buttons (Bp)

- Bp1 = Proportion of Push Buttons having a Diameter between 12 and 25 mm (0.5–1 in): **Bp1 = 13/16= 0.81.**
- Bp2 = Proportion of Push Buttons having a minimum Separation of 50 mm (2 in): **Bp2 = 2/16= 0.12.**
- FBp = Relative frequency of use for push buttons: **FBp = 0.23.**

$$FBp \cdot Bp = FBp \cdot (Bp1 + Bp2)/2$$

6. Hand–Levers (L)

- L1 = Proportion of Hand–Levers that require a maximum Activation Force of 16 kg (35 lbf): **L1 = 2/2= 1.**
- L2 = Proportion of Hand–Levers having a maximum Displacement of 355 mm (14 in): **L2 = 2/2= 1.**
- L3 = Proportion of Hand–Levers having a minimum Separation of 100 mm (4 in): **L3 = 2/2= 1.**
- L4 = Proportion of Hand–Levers that are located between 570 to 660 mm (22.4 to 26 in) covering a 90° envelope in front of the Seat Reference Point: **L4 = 1/2= 0.5.**
- FL = Relative frequency of use for hand–levers: **FL = 0.11.**

$$FL \cdot L = FL \cdot (L1 + L2 + L3 + L4)/4$$

7. Steering Wheel (Sw)

- Sw1 = If the Diameter is between 400 and 510 mm (15.7–20 in) then Sw1 = 1.
  - **Sw1 = 1.**
- Sw2 = If the Rim Thickness is between 19 and 32 mm (0.75–1.25 in) then Sw2=1.
  - **Sw2 = 1.**
- Sw3 = Proportion of any Hand–Levers located on steering wheel column that have a maximum vertical distance from the steering wheel to their top of 63.5 mm (2.5 in): **Sw3 = 1/2= 0.5.**
- Sw4 = If the Angle to the horizontal plane is between 40 and 60 degrees then Sw4=1.
  - **Sw4 = 0.3.**

$$Sw = (Sw1 + Sw2 + Sw3 + Sw4)/4$$

8. Multifunction Hand Controls (Mc)

- If a Multifunction Hand Control, which combines at least two control types and satisfies all the requirements, is presented, then its Ideal value will be equal to 1 = Mc.
  - **Mc = 1.**

9. Control Labeling (Lc)

- Lc1 = Proportion of controls having an associated title e.g. a label (*above the controls*) or indication *(e.g. icon, symbol)*: **Lc1 = 50/52= 0.96.**
- Lc2 = Colour – coding: If no more than four colours are used that are well spaced in chroma then Lc2 = 1.

  Lc2 = Colour – coding: Number of colours that are used: *3*, therefore **Lc2 = 1.**

$$Lc = (Lc1 + Lc2)/2$$

10. Functional Reach (Fr)

- Proportion of controls present within a radius of 750 mm (29.5 in) covering a 180° envelope in front of the operator:
  - **Fr = 30/52= 0.57.**

11. Suitability of Controls (Sc)

- Proportion of controls where mode of action is appropriate to function:
  - **Sc = 49/52= 0.94.**

12. Placement of Controls (Pc)

- Proportion of controls present on the right hand side of the operator:
  - **Pc = 46/52= 0.88.**

Calculations

$$I_F = \frac{(F_{Sr}\cdot Sr)+(F_{St}\cdot St)+(F_S\cdot S)+(F_{Kb}\cdot Kb)+(F_{Bp}\cdot Bp)+(F_L\cdot L)+(Ea)\cdot[(0.6\cdot Pc)+(0.48\cdot Sc)+(0.5\cdot Fr)+(0.42\cdot Lc)]+Sw+Mc}{\sum^{n} F+4}$$

- Rotary Switches = Sr = (Sr1 + Sr2 + Sr3 + Sr4)/4
  - F_{Sr} = relative frequency of use for rotary switches = 0.01.
  - Sr = (1+1+0+1)/4= 3/4= 0.75.
- Toggle Switches = St = (St1 + St2)/2
  - F_{St} = relative frequency of use for toggle switches = 0.13.
  - St = (0.9+0.6)/2= 1.5/2= 0.75.
- Rocker Switches = S = (S1 + S2 + S3)/3
  - F_S = relative frequency of use for rocker switches = 0.37.
  - S = (1+0.92+0.5)/3= 2.42/3= 0.80.
- Knobs = Kb = (Kb1 + Kb2 + Kb3)/3
  - F_{Kb} = relative frequency of use for knobs = 0.12.
  - Kb = (0.42+1+0.14)/3= 1.56/3= 0.52.
- Push Buttons = Bp = (Bp1 + Bp2)/2
  - F_{Bp} = relative frequency of use for push buttons = 0.23.

- Bp = (0.81+0.12)/2= 0.93/2= 0.46.

- Hand–Levers = L = (L1 + L2 + L3 + L4)/4
  - F_L = relative frequency of use for hand–levers = 0.11.
  - L = (1+1+1+0.5)/4= 3.5/4= 0.87.
- Steering Wheel = Sw = (Sw1 + Sw2 + Sw3 + Sw4)/4
  - Sw = (1+1+0.5+0.3)/4= 2.8/4= 0.7.
- Presence of Multifunction Hand Controls = Mc
  - Mc = 1.
- Placement of Controls = Pc
  - Pc = 0.88.
- Suitability of Controls = Sc
  - Sc = 0.94.
- Functional Reach = Fr
  - Fr = 0.57.
- Control Labeling = Lc = (Lc1 + Lc2)/2
  - Lc = (0.96+1)/2= 1.96/2= 0.98.
- Ea = Ergonomic factors average = [(Pc+Sc+Fr+Lc)/4] = 0.84.
- n =6 = Number of control types (maximum value n = 6, excluding Sw and Mc)

$$I_F=\frac{(0.01\cdot0.75)+(0.13\cdot0.75)+(0.37\cdot0.8)+(0.12\cdot0.52)+(0.23\cdot0.46)+(0.11\cdot0.87)+(0.84)\cdot[(0.6\cdot0.88)+(0.48\cdot0.94)+(0.5\cdot0.57)+(0.42\cdot0.98)]+(0.7)+(1)}{(0.01+0.13+0.37+0.12+0.23+0.11)+(4)}$$

$$I_F=\frac{(0.0075)+(0.09)+(0.29)+(0.06)+(0.10)+(0.09)+(0.84)\cdot[1.66]+(1.7)}{(0.97)+(4)}$$

$$I_F=\frac{(0.63)+(0.84)\cdot[1.66]+(1.7)}{(4.97)}$$

$$\mathbf{I_F= 0.75.}$$

Index of Functionality for the Buhler–Versatile 2210

1. Toggle Switches (St)

- St1 = Proportion of Toggle Switches having an Arm Length between 12 and 50 mm (0.5–2 in): **St1 = 4/4= 1.**
- St2 = Proportion of Toggle Switches having a minimum Separation of 50 mm (2 in): **St2 = 0/4= 0.**
- F_{St} = Relative frequency of use for toggle switches: **F_{St} = 0.04.**

$$FSt \cdot St = FSt \cdot (St1 + St2)/2$$

2. Rocker Switches (S)

- S1 = Proportion of Rocker Switches having a minimum Width of 6 mm (0.25 in): **S1 = 15/15= 1.**
- S2 = Proportion of Rocker Switches having a minimum Length of 12 mm (0.5 in): **S2 = 11/15= 0.73.**
- S3 = Proportion of Rocker Switches having a minimum Separation of 19 mm (0.75 in): **S3 = 11/15= 0.73.**
- F_S = Relative frequency of use for rocker switches: **F_S = 0.35.**

$$Fs \cdot S = Fs \cdot (S1+S2+S3)/3$$

3. Knobs (Kb)

- K_b1 = Proportion of Knobs having a Height between 12 and 25 mm (0.5–1 in): **Kb1 = 8/8= 1.**
- K_b2 = Proportion of Knobs having a Diameter between 12 and 100 mm (0.5–4 in):

  K_b2 = 8/8= 1.
- K_b3 = Proportion of Knobs having a minimum Separation of 50 mm (2 in): **K_b3 = 0/8= 0.**
- F_{Kb} = Relative frequency of use for knobs: **F_{Kb} = 0.17.**

$$FKb \cdot Kb = FKb \cdot (Kb1 + Kb2 + Kb3)/3$$

4. Push Buttons (Bp)

- Bp1 = Proportion of Push Buttons having a Diameter between 12 and 25 mm (0.5–1 in): **Bp1 = 19/24= 0.79.**
- Bp2 = Proportion of Push Buttons having a minimum Separation of 50 mm (2 in): **Bp2 = 4/24= 0.16.**
- F_{Bp} = Relative frequency of use for push buttons: **F_{Bp} = 0.39.**

$$F_{Bp} \cdot Bp = F_{Bp} \cdot (Bp1 + Bp2)/2$$

5. Hand–Levers (L)

- L1 = Proportion of Hand–Levers that require a maximum Activation Force of 16 kg (35 lbf): **L1 = 4/4= 1.**
- L2 = Proportion of Hand–Levers having a maximum Displacement of 355 mm (14 in): **L2 = 4/4= 1.**
- L3 = Proportion of Hand–Levers having a minimum Separation of 100 mm (4 in): **L3 = 1/4= 0.25.**
- L4 = Proportion of Hand–Levers that are located between 570 to 660 mm (22.4 to 26 in) covering a 90° envelope in front of the Seat Reference Point: **L4 = 4/4= 1.**
- F_L = Relative frequency of use for hand–levers: **F_L = 0.04.**

$$FL \cdot L = FL \cdot (L1 + L2 + L3 + L4)/4$$

6. Steering Wheel (Sw)

- Sw1 = If the Diameter is between 400 and 510 mm (15.7–20 in) then Sw1 = 1.
  - **Sw1 = 0.3.**
- Sw2 = If the Rim Thickness is between 19 and 32 mm (0.75–1.25 in) then Sw2 = 1.
  - **Sw2 = 1.**
- Sw3 = Proportion of any Hand–Levers located on steering wheel column that have a maximum vertical distance from the steering wheel to their top of 63.5 mm (2.5 in): **Sw3 = 1/2= 0.5.**

- Sw4 = If the Angle to the horizontal plane is between 40 and 60 degrees then Sw4 = 1.
  - **Sw4 = 1.**

$$Sw = (Sw1 + Sw2 + Sw3 + Sw4)/4$$

7. Multifunction Hand Controls (Mc)

- If a Multifunction Hand Control, which combines at least two control types and satisfies all the requirements, is presented, then the Multifunction Hand Control Ideal value will be equal to 1 = Mc.
  - **Mc = 1.**

8. Control Labeling (Lc)

- Lc1 = Proportion of controls having an associated title e.g. a label (*above the controls*) or indication *(e.g. icon, symbol)*: **Lc1 = 55/57= 0.96.**
- Lc2 = Colour – coding: If no more than four colours are used that are well spaced in chroma then Lc2 = 1.

  Lc2 = Colour – coding: Number of colours that are used: *7*, therefore **Lc2 = 0.3.**

$$Lc = (Lc1 + Lc2)/2$$

9. Functional Reach (Fr)

- Proportion of controls present within a radius of 750 mm (29.5 in) covering a 180° envelope in front of the operator: **Fr = 49/57= 0.85.**

10. Suitability of Controls (Sc)

- Proportion of controls where mode of action is appropriate to function: **Sc = 56/57= 0.98.**

11. Placement of Controls (Pc)

- Proportion of controls present on the right hand side of the operator: **Pc = 49/57= 0.85.**

Calculations

$$I_F = \frac{(F_{Sr}\cdot Sr)+(F_{St}\cdot St)+(F_S\cdot S)+(F_{Kb}\cdot Kb)+(F_{Bp}\cdot Bp)+(F_L\cdot L)+(Ea)\cdot[(0.6\cdot Pc)+(0.48\cdot Sc)+(0.5\cdot Fr)+(0.42\cdot Lc)]+Sw+Mc}{\sum^{n} F+4}$$

- Toggle Switches = St = (St1 + St2)/2
  - F_{St} = relative frequency of use for toggle switches = 0.04.
  - St = (1+0)/2= 1/2= 0.50.
- Rocker Switches = S = (S1 + S2 + S3)/3
  - F_S = relative frequency of use for rocker switches = 0.35.
  - S = (1+0.73+0.73)/3 = 2.46/3= 0.82.
- Knobs = Kb = (Kb1 + Kb2 + Kb3)/3
  - F_{Kb} = relative frequency of use for knobs = 0.17.
  - Kb = (1+1+0)/3= 2/3= 0.66.
- Push Buttons = Bp = (Bp1 + Bp2)/2
  - F_{Bp} = relative frequency of use for push buttons = 0.39.
  - Bp = (0.79+0.16)/2= 0.95/2= 0.47.
- Hand–Levers = L = (L1 + L2 + L3 + L4)/4
  - F_L = relative frequency of use for hand–levers = 0.04.
  - L = (1+1+0.25+1)/4=3.25/4= 0.81.
- Steering Wheel = Sw = (Sw1 + Sw2 + Sw3 + Sw4)/4
  - Sw = (0.3+1+0.5+1)/4= 2.8/4= 0.70.
- Presence of Multifunction Hand Controls = Mc
  - Mc = 1.
- Placement of Controls = Pc
  - Pc = 0.85.
- Suitability of Controls = Sc
  - Sc = 0.98.
- Functional Reach = Fr
  - Fr = 0.85.

- Control Labeling = Lc = (Lc1 + Lc2)/2
  - Lc = (0.96+0.3)/2= 1.26/2= 0.63.
- Ea = Ergonomic factors average = [(Pc+Sc+Fr+Lc)/4] = 0.82.
- n =5= Number of control types (maximum value n = 6, excluding Sw and Mc)

$$I_F = \frac{(0.04\cdot 0.5)+(0.35\cdot 0.82)+(0.17\cdot 0.66)+(0.39\cdot 0.47)+(0.04\cdot 0.81)+(0.82)\cdot[(0.6\cdot 0.85)+(0.48\cdot 0.98)+(0.5\cdot 0.85)+(0.42\cdot 0.63)]+(0.7)+(1)}{(0.04+0.35+0.17+0.39+0.04)+(4)}$$

$$I_F = \frac{(0.02)+(0.28)+(0.11)+(0.18)+(0.03)+(0.82)\cdot[1.66]+(0.7)+(1)}{(0.99)+(4)}$$

$$I_F = \frac{(0.62)+(0.82)\cdot[1.66]+(0.7)+(1)}{(4.99)}$$

$$\mathbf{I_F = 0.73.}$$

Index of Functionality for the New Holland TG 285

1. Rotary Switches (Sr)

- Sr1 = Proportion of Rotary Switches having a Length between 25 and 76 mm (1–4 in): **Sr1 = 1/1= 1.**
- Sr2 = Proportion of Rotary Switches having a Width up to 25 mm (1 in): **Sr2 = 1/1= 1.**
- Sr3 = Proportion of Rotary Switches having a Height between 12 and 75 mm (0.5–3 in): **Sr3 = 0/1= 0.**
- Sr4 = Proportion of Rotary Switches having a minimum Separation of 25 mm (1 in): **Sr4 = 1/1= 1.**
- F_{Sr} = Relative frequency of use for rotary switches: **F_{Sr} = 0.01.**

$$FSr \cdot Sr = FSr \cdot (Sr1 + Sr2 + Sr3 + Sr4)/4$$

2. Toggle Switches (St)

- St1 = Proportion of Toggle Switches having an Arm Length between 12 and 50 mm (0.5–2 in): **St1 = 9/10= 0.9.**
- St2 = Proportion of Toggle Switches having a minimum Separation of 50 mm (2 in): **St2 = 6/10= 0.6.**
- F_{St} = Relative frequency of use for toggle switches: **F_{St} = 0.12.**

$$FSt \cdot St = FSt \cdot (St1 + St2)/2$$

3. Rocker Switches (S)

- S1 = Proportion of Rocker Switches having a minimum Width of 6 mm (0.25 in): **S1 = 15/15= 1.**
- S2 = Proportion of Rocker Switches having a minimum Length of 12 mm (0.5 in): **S2 = 14/15= 0.93.**
- S3 = Proportion of Rocker Switches having a minimum Separation of 19 mm (0.75 in): **S3 = 7/15= 0.46.**
- Fs = Relative frequency of use for rocker switches: **Fs = 0.38.**

$$Fs \cdot S = Fs \cdot (S1+S2+S3)/3$$

4. Knobs (Kb)

- Kb1 = Proportion of Knobs having a Height between 12 and 25 mm (0.5–1 in): **Kb1 = 2/7= 0.28.**
- Kb2 = Proportion of Knobs having a Diameter between 12 and 100 mm (0.5–4 in): **Kb2 = 7/7= 1.**
- Kb3 = Proportion of Knobs having a minimum Separation of 50 mm (2 in): **Kb3=1/7=0.14.**
- FKb = Relative frequency of use for knobs: **FKb = 0.11.**

$$FKb \cdot Kb = FKb \cdot (Kb1 + Kb2 + Kb3)/3$$

5. Push Buttons (Bp)

- Bp1 = Proportion of Push Buttons having a Diameter between 12 and 25 mm (0.5–1 in): **Bp1 = 14/17= 0.82.**
- Bp2 = Proportion of Push Buttons having a minimum Separation of 50 mm (2 in): **Bp2 = 2/17= 0.11.**
- FBp = Relative frequency of use for push buttons: **FBp = 0.23.**

$$FBp \cdot Bp = FBp \cdot (Bp1 + Bp2)/2$$

6. Hand–Levers (L)

- L1 = Proportion of Hand–Levers that require a maximum Activation Force of 16 kg (35 lbf): **L1 = 2/2= 1.**
- L2 = Proportion of Hand–Levers having a maximum Displacement of 355 mm (14 in): **L2 = 2/2= 1.**
- L3 = Proportion of Hand–Levers having a minimum Separation of 100 mm (4 in): **L3 = 1/2= 0.5.**
- L4 = Proportion of Hand–Levers that are located between 570 to 660 mm (22.4 to 26 in) covering a 90° envelope in front of the Seat Reference Point: **L4 = 1/2= 0.5.**
- FL = Relative frequency of use for hand–levers: **FL = 0.11.**

$$FL \cdot L = FL \cdot (L1 + L2 + L3 + L4)/4$$

7. Steering Wheel (Sw)

- Sw1 = If the Diameter is between 400 and 510 mm (15.7–20 in) then Sw1 = 1.
  - **Sw1 = 1.**
- Sw2 = If the Rim Thickness is between 19 and 32 mm (0.75–1.25 in) then Sw2 = 1.
  - **Sw2 = 1.**
- Sw3 = Proportion of any Hand–Levers located on steering wheel column that have a maximum vertical distance from the steering wheel to their top of 63.5 mm (2.5 in): **Sw3 = 1/1= 1.**
- Sw4 = If the Angle to the horizontal plane is between 40 and 60 degrees then Sw4 = 1.
  - **Sw4 = 0.3.**

$$Sw = (Sw1 + Sw2 + Sw3 + Sw4)/4$$

8. Multifunction Hand Controls (Mc)

- If a Multifunction Hand Control, which combines at least two control types and satisfies all the requirements, is presented, then the Multifunction Hand Control Ideal value will be equal to 1 = Mc.
  - **Mc = 1.**

9. Control Labeling (Lc)

- Lc1 = Proportion of controls having an associated title e.g. a label (*above the controls*) or indication *(e.g. icon, symbol)*: **Lc1 = 52/54= 0.96.**
- Lc2 = Colour – coding: If no more than four colours are used that are well spaced in chroma then Lc2 = 1.

  Lc2 = Colour – coding: Number of colours that are used: *6*, therefore **Lc2 = 0.3.**

$$Lc = (Lc1 + Lc2)/2$$

10. Functional Reach (Fr)

- Proportion of controls present within a radius of 750 mm (29.5 in) covering a 180° envelope in front of the operator: **Fr = 31/54= 0.57.**

11. Suitability of Controls (Sc)

- Proportion of controls where mode of action is appropriate to function: **Sc = 51/54= 0.94.**

12. Placement of Controls (Pc)

- Proportion of controls present on the right hand side of the operator: **Pc = 49/54= 0.90.**

Calculations

$$I_F = \frac{(F_{Sr}\cdot Sr)+(F_{St}\cdot St)+(F_S\cdot S)+(F_{Kb}\cdot Kb)+(F_{Bp}\cdot Bp)+(F_L\cdot L)+(Ea)\cdot[(0.6\cdot Pc)+(0.48\cdot Sc)+(0.5\cdot Fr)+(0.42\cdot Lc)]+Sw+Mc}{\sum^{n} F+4}$$

- Rotary Switches = Sr = (Sr1 + Sr2 + Sr3 + Sr4)/4
  - F_{Sr} = relative frequency of use for rotary switches = 0.01.
  - Sr = (1+1+0+1)/4= 3/4= 0.75.
- Toggle Switches = St = (St1 + St2)/2
  - F_{St} = relative frequency of use for toggle switches = 0.12.
  - St = (0.9+0.6)/2= 1.5/2= 0.75.
- Rocker Switches = S = (S1 + S2 + S3)/3
  - F_S = relative frequency of use for rocker switches = 0.38.
  - S = (1+0.93+0.46)/3= 2.39/3= 0.79.
- Knobs = Kb = (Kb1 + Kb2 + Kb3)/3
  - F_{Kb} = relative frequency of use for knobs = 0.11.
  - Kb = (0.28+1+0.14)/3= 1.42/3= 0.47.
- Push Buttons = Bp = (Bp1 + Bp2)/2
  - F_{Bp} = relative frequency of use for push buttons = 0.23.
  - Bp = (0.82+0.11)/2 = 0.93/2= 0.46.

- Hand–Levers = L = (L1 + L2 + L3 + L4)/4
  - F_L = relative frequency of use for hand–levers = 0.11.
  - L= (1+1+0.5+0.5)/4 = 3/4= 0.75.
- Steering Wheel = Sw = (Sw1 + Sw2 + Sw3 + Sw4)/4
  - Sw = (1+1+1+0.3)/4= 3.3/4= 0.82.
- Presence of Multifunction Hand Controls = Mc
  - Mc = 1.
- Placement of Controls = Pc
  - Pc = 0.90.
- Suitability of Controls = Sc
  - Sc = 0.94.
- Functional Reach = Fr
  - Fr = 0.57.
- Control Labeling = Lc = (Lc1 + Lc2)/2
  - Lc = (0.96+0.3)/2= 1.26/2= 0.63.
- Ea = Ergonomic factors average = [(Pc+Sc+Fr+Lc)/4] = 0.76.
- n =6 = Number of control types (maximum value n = 6, excluding Sw and Mc)

$$I_F = \frac{(0.01\cdot 0.75)+(0.12\cdot 0.75)+(0.38\cdot 0.79)+(0.11\cdot 0.47)+(0.23\cdot 0.46)+(0.11\cdot 0.75)+(0.76)\cdot[(0.6\cdot 0.9)+(0.48\cdot 0.94)+(0.5\cdot 0.57)+(0.42\cdot 0.63)]+(0.82)+(1)}{(0.01+0.12+0.38+0.11+0.23+0.11)+(4)}$$

$$I_F = \frac{(0.0075)+(0.09)+(0.3)+(0.05)+(0.1)+(0.08)+(0.76)\cdot[1.53]+(0.82)+(1)}{(0.96)+(4)}$$

$$I_F = \frac{(0.62)+(0.76)\cdot[1.53]+(0.82)+(1)}{(4.96)}$$

$$\mathbf{I_F = 0.72.}$$

Index of Functionality for the Fendt 920 Vario

1. Rocker Switches (S)

- S1 = Proportion of Rocker Switches having a minimum Width of 6 mm (0.25 in): **S1 = 5/6= 0.83.**
- S2 = Proportion of Rocker Switches having a minimum Length of 12 mm (0.5 in): **S2 = 6/6= 1.**
- S3 = Proportion of Rocker Switches having a minimum Separation of 19 mm (0.75 in): **S3 = 5/6= 0.83.**
- Fs = Relative frequency of use for rocker switches: **Fs = 0.15.**

$$Fs \cdot S = Fs \cdot (S1+S2+S3)/3$$

2. Knobs (Kb)

- Kb1 = Proportion of Knobs having a Height between 12 and 25 mm (0.5–1 in): **Kb1 = 8/9= 0.88.**
- Kb2 = Proportion of Knobs having a Diameter between 12 and 100 mm (0.5–4 in): **Kb2 = 9/9= 1.**
- Kb3 = Proportion of Knobs having a minimum Separation of 50 mm (2 in): **Kb3 = 4/9= 0.44.**
- FKb = Relative frequency of use for knobs: **FKb = 0.13.**

$$FKb \cdot Kb = FKb \cdot (Kb1 + Kb2 + Kb3)/3$$

3. Push Buttons (Bp)

- Bp1 = Proportion of Push Buttons having a Diameter between 12 and 25 mm (0.5–1 in): **Bp1 = 49/52= 0.94.**
- Bp2 = Proportion of Push Buttons having a minimum Separation of 50 mm (2 in): **Bp2 = 1/52= 0.01.**
- FBp = Relative frequency of use for push buttons: **FBp = 0.53.**

$$FBp \cdot Bp = FBp \cdot (Bp1 + Bp2)/2$$

4. Hand–Levers (L)

- L1 = Proportion of Hand–Levers that require a maximum Activation Force of 16 kg (35 lbf): **L1 = 4/4= 1.**
- L2 = Proportion of Hand–Levers having a maximum Displacement of 355 mm (14 in): **L2 = 4/4= 1.**
- L3 = Proportion of Hand–Levers having a minimum Separation of 100 mm (4 in): **L3 = 4/4= 1.**
- L4 = Proportion of Hand–Levers that are located between 570 to 660 mm (22.4 to 26 in) covering a 90° envelope in front of the Seat Reference Point: **L4 = 1/4= 0.25.**
- F_L = Relative frequency of use for hand–levers: **F_L = 0.17.**

$$FL \cdot L = FL \cdot (L1 + L2 + L3 + L4)/4$$

5. Steering Wheel (Sw)

- Sw1 = If the Diameter is between 400 and 510 mm (15.7–20 in) then Sw1 = 1.
  - **Sw1 = 1.**
- Sw2 = If the Rim Thickness is between 19 and 32 mm (0.75–1.25 in) then Sw2 = 1.
  - **Sw2 = 1.**
- Sw3 = Proportion of any Hand–Levers located on steering wheel column that have a maximum vertical distance from the steering wheel to their top of 63.5 mm (2.5 in): **Sw3 = 0/2= 0.**
- Sw4 = If the Angle to the horizontal plane is between 40 and 60 degrees then Sw4 = 1.
  - **Sw4 = 1.**

$$Sw = (Sw1 + Sw2 + Sw3 + Sw4)/4$$

6. Multifunction Hand Controls (Mc)

- If a Multifunction Hand Control, which combines at least two control types and satisfies all the requirements, is presented, then the Multifunction Hand Control Ideal value will be equal to 1 = Mc.
  - **Mc = 1.**

7. Control Labeling (Lc)

- Lc1 = Proportion of controls having an associated title e.g. a label (*above the controls*) or indication *(e.g. icon, symbol)*: **Lc1 = 68/73= 0.93.**
- Lc2 = Colour – coding: If no more than four colours are used that are well spaced in chroma then Lc2 = 1.

  Lc2 = Colour – coding: Number of colours that are used: 7, therefore **Lc2 = 0.3.**

$$Lc = (Lc1 + Lc2)/2$$

8. Functional Reach (Fr)

- Proportion of controls present within a radius of 750 mm (29.5 in) covering a 180° envelope in front of the operator: **Fr = 48/73= 0.65.**

9. Suitability of Controls (Sc)

- Proportion of controls where mode of action is appropriate to function: **Sc = 69/73= 0.94.**

10. Placement of Controls (Pc)

- Proportion of controls present on the right hand side of the operator: **Pc = 63/73= 0.86.**

Calculations

$$I_F = \frac{(F_{Sr}\cdot Sr)+(F_{St}\cdot St)+(F_S\cdot S)+(F_{Kb}\cdot Kb)+(F_{Bp}\cdot Bp)+(F_L\cdot L)+(Ea)\cdot[(0.6\cdot Pc)+(0.48\cdot Sc)+(0.5\cdot Fr)+(0.42\cdot Lc)]+Sw+Mc}{\overset{n}{\Sigma} F+ 4}$$

- Rocker Switches = S = (S1 + S2 + S3)/3
  - Fs = relative frequency of use for rocker switches = 0.15.
  - S = (0.83+1+0.83)/3=2.66/3= 0.88.

- Knobs = Kb = (Kb1 + Kb2 + Kb3)/3
  - F_{Kb} = relative frequency of use for knobs = 0.13.
  - Kb = (0.88+1+0.44)/3= 2.32/3= 0.77.
- Push Buttons = Bp = (Bp1 + Bp2)/2
  - F_{Bp} = relative frequency of use for push buttons = 0.53.
  - Bp= (0.94+0.01)/2= 0.95/2= 0.47.
- Hand–Levers = L = (L1 + L2 + L3 + L4)/4
  - F_L = relative frequency of use for hand–levers = 0.17.
  - L = (1+1+1+0.25)/4= 3.25/4= 0.81.
- Steering Wheel = Sw = (Sw1 + Sw2 + Sw3 + Sw4)/4
  - Sw = (1+1+0+1)/4= 3/4= 0.75.
- Presence of Multifunction Hand Controls = Mc
  - Mc = 1.
- Placement of Controls = Pc
  - Pc = 0.86.
- Suitability of Controls = Sc
  - Sc = 0.94.
- Functional Reach = Fr
  - Fr = 0.65.
- Control Labeling = Lc = (Lc1 + Lc2)/2
  - Lc = (0.93+0.3)/2= 1.23/2= 0.61.
- Ea = Ergonomic factors average = [(Pc+Sc+Fr+Lc)/4] = 0.76.
- n =4= Number of control types (maximum value n = 6, excluding Sw and Mc)

$$I_F = \frac{(0.15\cdot0.88)+(0.13\cdot0.77)+(0.53\cdot0.47)+(0.17\cdot0.81)+(0.76)\cdot[(0.6\cdot0.86)+(0.48\cdot0.94)+(0.5\cdot0.65)+(0.42\cdot0.61)]+(0.75)+(1)}{(0.15+0.13+0.53+0.17)+(4)}$$

$$I_F = \frac{(0.13)+(0.1)+(0.24)+(0.13)+(0.76)\cdot[1.53]+(0.75)+(1)}{(0.98)+(4)}$$

$$I_F = \frac{(0.6)+(0.76)\cdot[1.53]+(0.75)+(1)}{(4.98)}$$

$$\mathbf{I_F = 0.70.}$$

Index of Functionality for the Caterpillar Challenger MT665B

1. Toggle Switches (St)

- St1 = Proportion of Toggle Switches having an Arm Length between 12 and 50 mm (0.5–2 in): **St1 = 4/4= 1.**
- St2 = Proportion of Toggle Switches having a minimum Separation of 50 mm (2 in): **St2 = 0/4= 0.**
- F_{St} = Relative frequency of use for toggle switches: **F_{St} = 0.03.**

$$FSt \cdot St = FSt \cdot (St1 + St2)/2$$

2. Rocker Switches (S)

- S1 = Proportion of Rocker Switches having a minimum Width of 6 mm (0.25 in): **S1 = 11/11= 1.**
- S2 = Proportion of Rocker Switches having a minimum Length of 12 mm (0.5 in): **S2 = 11/11= 1.**
- S3 = Proportion of Rocker Switches having a minimum Separation of 19 mm (0.75 in): **S3 = 2/11= 0.18.**
- Fs = Relative frequency of use for rocker switches: **Fs = 0.22.**

$$Fs \cdot S=Fs \cdot (S1+S2+S3)/3$$

3. Knobs (Kb)

- Kb1 = Proportion of Knobs having a Height between 12 and 25 mm (0.5–1 in): **Kb1 = 8/10= 0.8.**
- Kb2 = Proportion of Knobs having a Diameter between 12 and 100 mm (0.5–4 in): **Kb2 = 10/10= 1.**
- Kb3 = Proportion of Knobs having a minimum Separation of 50 mm (2 in): **Kb3 = 1/10= 0.1.**
- F_{Kb} = Relative frequency of use for knobs: **F_{Kb} = 0.11.**

$$FKb \cdot Kb = FKb \cdot (Kb1 + Kb2 + Kb3)/3$$

4. Push Buttons (Bp)

- Bp1 = Proportion of Push Buttons having a Diameter between 12 and 25 mm (0.5–1 in): **Bp1 = 33/37= 0.89.**
- Bp2 = Proportion of Push Buttons having a minimum Separation of 50 mm (2 in): **Bp2 = 5/37= 0.13.**
- F_{Bp} = Relative frequency of use for push buttons: **F_{Bp} = 0.41.**

$$FBp \cdot Bp = FBp \cdot (Bp1 + Bp2)/2$$

5. Hand–Levers (L)

- L1 = Proportion of Hand–Levers that require a maximum Activation Force of 16 kg (35 lbf): **L1 = 7/7= 1.**
- L2 = Proportion of Hand–Levers having a maximum Displacement of 355 mm (14 in): **L2 = 7/7= 1.**
- L3 = Proportion of Hand–Levers having a minimum Separation of 100 mm (4 in): **L3 = 1/7= 0.14.**
- L4 = Proportion of Hand–Levers that are located between 570 to 660 mm (22.4 to 26 in) covering a 90° envelope in front of the Seat Reference Point: **L4 = 4/7= 0.57.**
- F_L = Relative frequency of use for hand–levers: **F_L = 0.22.**

$$FL \cdot L = FL \cdot (L1 + L2 + L3 + L4)/4$$

6. Steering Wheel (Sw)

- Sw1 = If the Diameter is between 400 and 510 mm (15.7–20 in) then Sw1 = 1.
  - **Sw1 = 0.3.**
- Sw2 = If the Rim Thickness is between 19 and 32 mm (0.75–1.25 in) then Sw2 = 1.
  - **Sw2 = 1.**
- Sw3 = Proportion of any Hand–Levers located on steering wheel column that have a maximum vertical distance from the steering wheel to their top of 63.5 mm (2.5 in): **Sw3 = 1/3= 0.33.**

- Sw4 = If the Angle to the horizontal plane is between 40 and 60 degrees then Sw4 = 1.
  - **Sw4 = 1.**

$$Sw = (Sw1 + Sw2 + Sw3 + Sw4)/4$$

7. Control Labeling (Lc)

- Lc1 = Proportion of controls having an associated title e.g. a label (*above the controls*) or indication *(e.g. icon, symbol)*: **Lc1 = 66/70= 0.94.**
- Lc2 = Colour – coding: If no more than four colours are used that are well spaced in chroma then Lc2 = 1.

  Lc2 = Colour – coding: Number of colours that are used: *5*, therefore **Lc2 = 0.3.**

$$Lc = (Lc1 + Lc2)/2$$

8. Functional Reach (Fr)

- Proportion of controls present within a radius of 750 mm (29.5 in) covering a 180° envelope in front of the operator: **Fr = 64/70= 0.91.**

9. Suitability of Controls (Sc)

- Proportion of controls where mode of action is appropriate to function: **Sc = 70/70= 1.**

10. Placement of Controls (Pc)

- Proportion of controls present on the right hand side of the operator: **Pc = 63/70= 0.9.**

Calculations

$$I_F = \frac{(F_{Sr}\cdot Sr)+(F_{St}\cdot St)+(F_S\cdot S)+(F_{Kb}\cdot Kb)+(F_{Bp}\cdot Bp)+(F_L\cdot L)+(Ea)\cdot[(0.6\cdot Pc)+(0.48\cdot Sc)+(0.5\cdot Fr)+(0.42\cdot Lc)]+Sw+Mc}{\sum^{n} F+4}$$

- Toggle Switches = St = (St1 + St2)/2
  - F_{St} = relative frequency of use for toggle switches = 0.03.
  - St = (1+0)/2= 1/2= 0.50
- Rocker Switches = S = (S1 + S2 + S3)/3
  - F_S = relative frequency of use for rocker switches = 0.22.
  - S = (1+1+0.18)/3= 2.18/3= 0.72.
- Knobs = Kb = (Kb1 + Kb2 + Kb3)/3
  - F_{Kb} = relative frequency of use for knobs = 0.11.
  - Kb = (0.8+1+0.1)/3= 1.9/3= 0.63.
- Push Buttons = Bp = (Bp1 + Bp2)/2
  - F_{Bp} = relative frequency of use for push buttons = 0.41.
  - Bp = (0.89+0.13)/2= 1.02/2= 0.51.
- Hand–Levers = L = (L1 + L2 + L3 + L4)/4
  - F_L = relative frequency of use for hand–levers = 0.22.
  - L = (1+1+0.14+0.57)/4= 2.71/4= 0.67.
- Steering Wheel = Sw = (Sw1 + Sw2 + Sw3 + Sw4)/4
  - Sw = (0.3+1+0.33+1)/4= 2.63/4= 0.65.
- Placement of Controls = Pc
  - Pc = 0.90.
- Suitability of Controls = Sc
  - Sc = 1.
- Functional Reach = Fr
  - Fr = 0.91.
- Control Labeling = Lc = (Lc1 + Lc2)/2
  - Lc = (0.94+0.3)/2= 1.24/2= 0.62.
- Ea = Ergonomic factors average = [(Pc+Sc+Fr+Lc)/4] = 0.85.

- n = 5 = Number of control types (maximum value n = 6, excluding Sw and Mc)

$$I_F = \frac{(0.03\cdot0.5)+(0.22\cdot0.72)+(0.11\cdot0.63)+(0.41\cdot0.51)+(0.22\cdot0.67)+(0.85)\cdot[(0.6\cdot0.9)+(0.48\cdot1)+(0.5\cdot0.91)+(0.42\cdot0.62)]+(0.65)}{(0.03+0.22+0.11+0.41+0.22)+(4)}$$

$$I_F = \frac{(0.015)+(0.15)+(0.07)+(0.2)+(0.14)+(0.85)\cdot[1.73]+(0.65)}{(0.99)+(4)}$$

$$I_F = \frac{(0.57)+(0.85)\cdot[1.73]+(0.65)}{(4.99)}$$

$$\mathbf{I_F = 0.54.}$$

Index of Functionality for the Fendt 275 S

1. Toggle Switches (St)

- St1 = Proportion of Toggle Switches having an Arm Length between 12 and 50 mm (0.5–2 in): **St1 = 0/1= 0.**
- St2 = Proportion of Toggle Switches having a minimum Separation of 50 mm (2 in): **St2 = 0/1= 0.**
- F_{St} = Relative frequency of use for toggle switches: **F_{St} = 0.09.**

$$FSt \cdot St = FSt \cdot (St1 + St2)/2$$

2. Rocker Switches (S)

- S1 = Proportion of Rocker Switches having a minimum Width of 6 mm (0.25 in): **S1 = 0/1= 0.**
- S2 = Proportion of Rocker Switches having a minimum Length of 12 mm (0.5 in): **S2 = 1/1= 1.**
- S3 = Proportion of Rocker Switches having a minimum Separation of 19 mm (0.75 in): **S3 = 0/1= 0.**
- F_S = Relative frequency of use for rocker switches: **F_S = 0.06.**

$$Fs \cdot S=Fs \cdot (S1+S2+S3)/3$$

3. Knobs (Kb)

- K_b1 = Proportion of Knobs having a Height between 12 and 25 mm (0.5–1 in): **K_b1 = 2/3= 0.66.**
- K_b2 = Proportion of Knobs having a Diameter between 12 and 100 mm (0.5–4 in): **K_b2 = 1/3= 0.33.**
- K_b3 = Proportion of Knobs having a minimum Separation of 50 mm (2 in): **K_b3=2/3=0.66.**
- F_{Kb} = Relative frequency of use for knobs: **F_{Kb} = 0.18.**

$$FKb \cdot Kb = FKb \cdot (Kb1 + Kb2 + Kb3)/3$$

4. Push Buttons (Bp)

- Bp1 = Proportion of Push Buttons having a Diameter between 12 and 25 mm (0.5–1 in): **Bp1 = 3/4= 0.75.**
- Bp2 = Proportion of Push Buttons having a minimum Separation of 50 mm (2 in): **Bp2 = 3/4= 0.75.**
- FBp = Relative frequency of use for push buttons: **FBp = 0.15.**

$$FBp \cdot Bp = FBp \cdot (Bp1 + Bp2)/2$$

5. Hand–Levers (L)

- L1 = Proportion of Hand–Levers that require a maximum Activation Force of 16 kg (35 lbf): **L1 = 6/7= 0.85.**
- L2 = Proportion of Hand–Levers having a maximum Displacement of 355 mm (14 in): **L2 = 6/7= 0.85.**
- L3 = Proportion of Hand–Levers having a minimum Separation of 100 mm (4 in): **L3 = 2/7= 0.28.**
- L4 = Proportion of Hand–Levers that are located between 570 to 660 mm (22.4 to 26 in) covering a 90° envelope in front of the Seat Reference Point: **L4 = 3/7= 0.42.**
- FL = Relative frequency of use for hand–levers: **FL = 0.5.**

$$FL \cdot L = FL \cdot (L1 + L2 + L3 + L4)/4$$

6. Steering Wheel (Sw)

- Sw1 = If the Diameter is between 400 and 510 mm (15.7–20 in) then Sw1 = 1.
  - **Sw1 = 0.3.**
- Sw2 = If the Rim Thickness is between 19 and 32 mm (0.75–1.25 in) then Sw2 = 1.
  - **Sw2 = 0.3.**
- Sw3 = Proportion of any Hand–Levers located on steering wheel column that have a maximum vertical distance from the steering wheel to their top of 63.5 mm (2.5 in): **Sw3 = 0/2= 0.**

- Sw4 = If the Angle to the horizontal plane is between 40 and 60 degrees then Sw4 = 1.
  - **Sw4 = 1.**

$$Sw = (Sw1 + Sw2 + Sw3 + Sw4)/4$$

7. Control Labeling (Lc)

- Lc1 = Proportion of controls having an associated title e.g. a label (*above the controls*) or indication *(e.g. icon, symbol)*: **Lc1 = 11/17= 0.64.**
- Lc2 = Colour – coding: If no more than four colours are used that are well spaced in chroma then Lc2 = 1.

  Lc2 = Colour – coding: Number of colours that are used: *3*, therefore **Lc2 = 1.**

$$Lc = (Lc1 + Lc2)/2$$

8. Functional Reach (Fr)

- Proportion of controls present within a radius of 750 mm (29.5 in) covering a 180° envelope in front of the operator: **Fr = 9/17= 0.52.**

9. Suitability of Controls (Sc)

- Proportion of controls where mode of action is appropriate to function: **Sc = 10/17= 0.58.**

10. Placement of Controls (Pc)

- Proportion of controls present on the right hand side of the operator: **Pc = 9/17= 0.52.**

Calculations

$$I_F = \frac{(F_{Sr}\cdot Sr)+(F_{St}\cdot St)+(F_S\cdot S)+(F_{Kb}\cdot Kb)+(F_{Bp}\cdot Bp)+(F_L\cdot L)+(Ea)\cdot[(0.6\cdot Pc)+(0.48\cdot Sc)+(0.5\cdot Fr)+(0.42\cdot Lc)]+Sw+Mc}{\sum^{n} F+4}$$

- Toggle Switches = St = (St1 + St2)/2
  - F_{St} = relative frequency of use for toggle switches = 0.09.
  - St = (0+0)/2= 0.
- Rocker Switches = S = (S1 + S2 + S3)/3
  - F_S = relative frequency of use for rocker switches = 0.06.
  - S = (0+1+0)/3= 1/3 = 0.33.
- Knobs = Kb = (Kb1 + Kb2 + Kb3)/3
  - F_{Kb} = relative frequency of use for knobs = 0.18.
  - Kb = (0.66+0.33+0.66)/3= 1.65/3= 0.55.
- Push Buttons = Bp = (Bp1 + Bp2)/2
  - F_{Bp} = relative frequency of use for push buttons = 0.15.
  - Bp= (0.75+0.75)/2= 1.5/2= 0.75.
- Hand–Levers = L = (L1 + L2 + L3 + L4)/4
  - F_L = relative frequency of use for hand–levers = 0.50.
  - L = (0.85+0.85+0.28+0.42)/4= 2.4/4= 0.60.
- Steering Wheel = Sw = (Sw1 + Sw2 + Sw3 + Sw4)/4
  - Sw = (0.3+0.3+0+1)/4= 1.6/4= 0.40.
- Placement of Controls = Pc
  - Pc = 0.52.
- Suitability of Controls = Sc
  - Sc = 0.58.
- Functional Reach = Fr
  - Fr= 0.52.
- Control Labeling = Lc = (Lc1 + Lc2)/2
  - Lc = (0.64+1)/2= 1.64/2= 0.82.
- Ea = Ergonomic factors average = [(Pc+Sc+Fr+Lc)/4] = 0.61.

- n =5 = Number of control types (maximum value n = 6, excluding Sw and Mc)

$$I_F = \frac{(0.09\cdot 0)+(0.06\cdot 0.33)+(0.18\cdot 0.55)+(0.15\cdot 0.75)+(0.5\cdot 0.6)+(0.61)\cdot[(0.6\cdot 0.52)+(0.48\cdot 0.58)+(0.5\cdot 0.52)+(0.42\cdot 0.82)]+(0.4)}{(0.09+0.06+0.18+0.15+0.5)+(4)}$$

$$I_F = \frac{(0.01)+(0.09)+(0.11)+(0.3)+(0.61)\cdot[1.18]+(0.4)}{(0.98)+(4)}$$

$$I_F = \frac{(0.51)+(0.61)\cdot[1.18]+(0.4)}{(4.98)}$$

$$\mathbf{I_F = 0.32.}$$

Index of Functionality for the Hurlimann H – 478

1. Toggle Switches (St)

- St1 = Proportion of Toggle Switches having an Arm Length between 12 and 50 mm (0.5–2 in): **St1 = 0/1= 0.**
- St2 = Proportion of Toggle Switches having a minimum Separation of 50 mm (2 in): **St2 = 0/1= 0.**
- F_{St} = Relative frequency of use for toggle switches: **F_{St} = 0.07.**

$$FSt \cdot St = FSt \cdot (St1 + St2)/2$$

2. Rocker Switches (S)

- S1 = Proportion of Rocker Switches having a minimum Width of 6 mm (0.25 in): **S1 = 2/2= 1.**
- S2 = Proportion of Rocker Switches having a minimum Length of 12 mm (0.5 in): **S2 = 2/2= 1.**
- S3 = Proportion of Rocker Switches having a minimum Separation of 19 mm (0.75 in): **S3 = 0/2= 0.**
- F_S = Relative frequency of use for rocker switches: **F_S = 0.1.**

$$Fs \cdot S=Fs \cdot (S1+S2+S3)/3$$

3. Knobs (Kb)

- Kb1 = Proportion of Knobs having a Height between 12 and 25 mm (0.5–1 in): **Kb1 = 1/2= 0.5.**
- Kb2 = Proportion of Knobs having a Diameter between 12 and 100 mm (0.5–4 in): **Kb2 = 1/2= 0.5.**
- Kb3 = Proportion of Knobs having a minimum Separation of 50 mm (2 in): **Kb3 = 1/2= 0.5.**
- F_{Kb} = Relative frequency of use for knobs: **F_{Kb} = 0.25.**

$$FKb \cdot Kb = FKb \cdot (Kb1 + Kb2 + Kb3)/3$$

4. Push Buttons (Bp)

- Bp1 = Proportion of Push Buttons having a Diameter between 12 and 25 mm (0.5–1 in): **Bp1 = 0/1= 0.**
- Bp2 = Proportion of Push Buttons having a minimum Separation of 50 mm (2 in): **Bp2 = 1/1= 1.**
- FBp = Relative frequency of use for push buttons: **FBp = 0.02.**

$$FBp \cdot Bp = FBp \cdot (Bp1 + Bp2)/2$$

5. Hand–Levers (L)

- L1 = Proportion of Hand–Levers that require a maximum Activation Force of 16 kg (35 lbf): **L1 = 7/11= 0.63.**
- L2 = Proportion of Hand–Levers having a maximum Displacement of 355 mm (14 in): **L2 = 4/11= 0.36.**
- L3 = Proportion of Hand–Levers having a minimum Separation of 100 mm (4 in): **L3 = 2/11= 0.18.**
- L4 = Proportion of Hand–Levers that are located between 570 to 660 mm (22.4 to 26 in) covering a 90° envelope in front of the Seat Reference Point: **L4 = 6/11= 0.54.**
- FL = Relative frequency of use for hand–levers: **FL = 0.55.**

$$FL \cdot L = FL \cdot (L1 + L2 + L3 + L4)/4$$

6. Steering Wheel (Sw)

- Sw1 = If the Diameter is between 400 and 510 mm (15.7–20 in) then Sw1 = 1.
  - **Sw1 = 0.3.**
- Sw2 = If the Rim Thickness is between 19 and 32 mm (0.75–1.25 in) then Sw2 = 1.
  - **Sw2 = 0.3.**
- Sw3 = Proportion of any Hand–Levers located on steering wheel column that have a maximum vertical distance from the steering wheel to their top of 63.5 mm (2.5 in): **Sw3 = 0/2= 0.**

- Sw4 = If the Angle to the horizontal plane is between 40 and 60 degrees then Sw4 = 1.
  - **Sw4 = 1.**

$$Sw = (Sw1 + Sw2 + Sw3 + Sw4)/4$$

7. Control Labeling (Lc)

- Lc1 = Proportion of controls having an associated title e.g. a label (*above the controls*) or indication *(e.g. icon, symbol)*: **Lc1 = 8/18= 0.44.**
- Lc2 = Colour – coding: If no more than four colours are used that are well spaced in chroma then Lc2 = 1.

  Lc2 = Colour – coding: Number of colours that are used: *5*, therefore **Lc2 = 0.3.**

$$Lc = (Lc1 + Lc2)/2$$

8. Functional Reach (Fr)

- If a Multifunction Hand Control, which combines at least two control types and satisfies all the requirements, is presented, then the Multifunction Hand Control Ideal value will be equal to 1 = Mc.
  - **Mc = 1.**

9. Suitability of Controls (Sc)

- Proportion of controls where mode of action is appropriate to function: **Sc = 9/18= 0.5.**

10. Placement of Controls (Pc)

- Proportion of controls present on the right hand side of the operator: **Pc = 8/18= 0.44.**

Calculations

$$I_F = \frac{(F_{Sr}\cdot Sr)+(F_{St}\cdot St)+(F_S\cdot S)+(F_{Kb}\cdot Kb)+(F_{Bp}\cdot Bp)+(F_L\cdot L)+(Ea)\cdot[(0.6\cdot Pc)+(0.48\cdot Sc)+(0.5\cdot Fr)+(0.42\cdot Lc)]+Sw+Mc}{\sum^{n} F + 4}$$

- Toggle Switches = St = (St1 + St2)/2
  - F_{St} = relative frequency of use for toggle switches = 0.07.
  - St = (0+0)/2 = 0.
- Rocker Switches = S = (S1 + S2 + S3)/3
  - F_S = relative frequency of use for rocker switches = 0.10.
  - S = (1+1+0)/3= 2/3= 0.66.
- Knobs = Kb = (Kb1 + Kb2 + Kb3)/3
  - F_{Kb} = relative frequency of use for knobs = 0.25.
  - Kb = (0.5+0.5+0.5)/3= 1.5/3= 0.50.
- Push Buttons = Bp = (Bp1 + Bp2)/2
  - F_{Bp} = relative frequency of use for push buttons = 0.02.
  - Bp = (0+1)/2= 1/2= 0.50.
- Hand–Levers = L = (L1 + L2 + L3 + L4)/4
  - F_L = relative frequency of use for hand–levers = 0.55.
  - L = (0.63+0.36+0.18+0.54)/4= 1.71/4= 0.42.
- Steering Wheel = Sw = (Sw1 + Sw2 + Sw3 + Sw4)/4
  - Sw = (0.3+0.3+0+1)/4= 1.6/4= 0.40.
- Placement of Controls = Pc
  - Pc = 0.44.
- Suitability of Controls = Sc
  - Sc = 0.50.
- Functional Reach = Fr
  - Fr = 0.50.
- Control Labeling = Lc = (Lc1 + Lc2)/2
  - Lc = (0.44+0.3)/2= 0.74/2= 0.37.
- Ea = Ergonomic factors average = [(Pc+Sc+Fr+Lc)/4] = 0.45.

- n =5 = Number of control types (maximum value n = 6, excluding Sw and Mc)

$$I_F = \frac{(0.07\cdot 0)+(0.1\cdot 0.66)+(0.25\cdot 0.5)+(0.02\cdot 0.5)+(0.55\cdot 0.42)+(0.45)\cdot[(0.6\cdot 0.44)+(0.48\cdot 0.5)+(0.5\cdot 0.50)+(0.42\cdot 0.37)]+(0.4)}{(0.07+0.1+0.25+0.02+0.55)+(4)}$$

$$I_F = \frac{(0.066)+(0.125)+(0.01)+(0.23)+(0.45)\cdot[0.9]+(0.4)}{(0.99)+(4)}$$

$$I_F = \frac{(0.43)+(0.45)\cdot[0.9]+(0.4)}{(4.99)}$$

$$\mathbf{I_F = 0.24.}$$

Index of Functionality for the Agrifull-Fiatagri 65

1. Rotary Switches (Sr)

- Sr1 = Proportion of Rotary Switches having a Length between 25 and 76 mm (1–4 in): **Sr1 = 0/1= 0.**
- Sr2 = Proportion of Rotary Switches having a Width up to 25 mm (1 in): **Sr2 = 1/1= 1.**
- Sr3 = Proportion of Rotary Switches having a Height between 12 and 75 mm (0.5–3 in): **Sr3 = 0/1= 0.**
- Sr4 = Proportion of Rotary Switches having a minimum Separation of 25 mm (1 in): **Sr4 = 1/1= 1.**
- FSr = Relative frequency of use for rotary switches: **FSr = 0.04.**

$$FSr \cdot Sr = FSr \cdot (Sr1 + Sr2 + Sr3 + Sr4)/4$$

2. Toggle Switches (St)

- St1 = Proportion of Toggle Switches having an Arm Length between 12 and 50 mm (0.5–2 in): **St1 = 1/1= 1.**
- St2 = Proportion of Toggle Switches having a minimum Separation of 50 mm (2 in): **St2 = 0/1= 0.**
- FSt = Relative frequency of use for toggle switches: **FSt = 0.04.**

$$FSt \cdot St = FSt \cdot (St1 + St2)/2$$

3. Knobs (Kb)

- Kb1 = Proportion of Knobs having a Height between 12 and 25 mm (0.5–1 in): **Kb1 = 0/3= 0.**
- Kb2 = Proportion of Knobs having a Diameter between 12 and 100 mm (0.5–4 in): **Kb2 = 0/3= 0.**
- Kb3 = Proportion of Knobs having a minimum Separation of 50 mm (2 in): **Kb3=1/3=0.33.**
- FKb = Relative frequency of use for knobs: **FKb = 0.12.**

$$FKb \cdot Kb = FKb \cdot (Kb1 + Kb2 + Kb3)/3$$

4. Push Buttons (Bp)

- Bp1 = Proportion of Push Buttons having a Diameter between 12 and 25 mm (0.5–1 in): **Bp1 = 1/4= 0.25.**
- Bp2 = Proportion of Push Buttons having a minimum Separation of 50 mm (2 in): **Bp2 = 1/4= 0.25.**
- FBp = Relative frequency of use for push buttons: **FBp = 0.16.**

$$FBp \cdot Bp = FBp \cdot (Bp1 + Bp2)/2$$

5. Hand–Levers (L)

- L1 = Proportion of Hand–Levers that require a maximum Activation Force of 16 kg (35 lbf): **L1 = 3/7= 0.42.**
- L2 = Proportion of Hand–Levers having a maximum Displacement of 355 mm (14 in): **L2 = 2/7= 0.28.**
- L3 = Proportion of Hand–Levers having a minimum Separation of 100 mm (4 in): **L3 = 0/7= 0.**
- L4 = Proportion of Hand–Levers that are located between 570 to 660 mm (22.4 to 26 in) covering a 90° envelope in front of the Seat Reference Point: **L4 = 3/7= 0.42.**
- FL = Relative frequency of use for hand–levers: **FL = 0.62.**

$$FL \cdot L = FL \cdot (L1 + L2 + L3 + L4)/4$$

6. Steering Wheel (Sw)

- Sw1 = If the Diameter is between 400 and 510 mm (15.7–20 in) then Sw1 = 1.
  - **Sw1 = 0.3.**
- Sw2 = If the Rim Thickness is between 19 and 32 mm (0.75–1.25 in) then Sw2 = 1.
  - **Sw2 = 0.3.**
- Sw3 = Proportion of any Hand–Levers located on steering wheel column that have a maximum vertical distance from the steering wheel to their top of 63.5 mm (2.5 in): **Sw3= 0/1= 0.**

- Sw4 = If the Angle to the horizontal plane is between 40 and 60 degrees then Sw4=1.
    - **Sw4 = 0.3.**

$$Sw = (Sw1 + Sw2 + Sw3 + Sw4)/4$$

7. Control Labeling (Lc)

- Lc1 = Proportion of controls having an associated title e.g. a label (*above the controls*) or indication *(e.g. icon, symbol)*: **Lc1= 7/17= 0.41.**
- Lc2 = Colour – coding: If no more than four colours are used that are well spaced in chroma then Lc2 = 1.
    - Lc2 = Colour – coding: Number of colours that are used: *2*, therefore **Lc2= 1.**

$$Lc = (Lc1 + Lc2)/2$$

8. Functional Reach (Fr)

- Proportion of controls present within a radius of 750 mm (29.5 in) covering a 180° envelope in front of the operator:
    - **Fr= 9/17= 0.52.**

9. Suitability of Controls (Sc)

- Proportion of controls where mode of action is appropriate to function:
    - **Sc= 10/17= 0.58.**

10. Placement of Controls (Pc)

- Proportion of controls present on the right hand side of the operator:
    - **Pc= 5/17= 0.29.**

Calculations

$$I_F = \frac{(F_{Sr}\cdot Sr)+(F_{St}\cdot St)+(F_S\cdot S)+(F_{Kb}\cdot Kb)+(F_{Bp}\cdot Bp)+(F_L\cdot L)+(Ea)\cdot[(0.6\cdot Pc)+(0.48\cdot Sc)+(0.5\cdot Fr)+(0.42\cdot Lc)]+Sw+Mc}{\sum^{n} F + 4}$$

- Rotary Switches = Sr = (Sr1 + Sr2 + Sr3 + Sr4)/4
  - F_{Sr} = relative frequency of use for rotary switches = 0.04.
  - Sr = (0+1+0+1)/4= 2/4= 0.50.
- Toggle Switches = St = (St1 + St2)/2
  - F_{St} = relative frequency of use for toggle switches= 0.04.
  - St = (1+0)/2= 1/2= 0.50.
- Knobs = Kb = (Kb1 + Kb2 + Kb3)/3
  - F_{Kb} = relative frequency of use for knobs= 0.12.
  - Kb = (0+0+0.33)/3= 0.33/3= 0.11.
- Push Buttons = Bp = (Bp1 + Bp2)/2
  - F_{Bp} = relative frequency of use for push buttons= 0.16.
  - Bp = (0.25+0.25)/2= 0.5/2= 0.25.
- Hand–Levers = L = (L1 + L2 + L3 + L4)/4
  - F_L = relative frequency of use for hand–levers= 0.62.
  - L = (0.42+0.28+0+0.42)/4= 1.12/4= 0.28.
- Steering Wheel = Sw = (Sw1 + Sw2 + Sw3 + Sw4)/4
  - Sw = (0.3+0.3+0+0.3)/4= 0.9/4= 0.22.
- Placement of Controls = Pc
  - Pc = 0.29.
- Suitability of Controls = Sc
  - Sc = 0.58.
- Functional Reach = Fr
  - Fr = 0.52.
- Control Labeling = Lc = (Lc1 + Lc2)/2
  - Lc = (0.41+1)/2 = 1.41/2= 0.70.
- Ea = Ergonomic factors average = [(Pc+Sc+Fr+Lc)/4] = 0.52.

- n= 5 = Number of control types (maximum value n= 6, excluding Sw and Mc)

$$I_F = \frac{(0.04 \cdot 0.5)+(0.04 \cdot 0.5)+(0.12 \cdot 0.11)+(0.16 \cdot 0.25)+(0.62 \cdot 0.28)+(0.52) \cdot [(0.6 \cdot 0.29)+(0.48 \cdot 0.58)+(0.5 \cdot 0.52)+(0.42 \cdot 0.7)]+(0.22)}{(0.04+0.04+0.12+0.16+0.62)+(4)}$$

$$I_F = \frac{(0.02)+(0.02)+(0.01)+(0.04)+(0.17)+(0.52) \cdot [0.99]+(0.22)}{(0.98)+(4)}$$

$$I_F = \frac{(0.26)+(0.52) \cdot [0.99]+(0.22)}{(4.98)}$$

$$\mathbf{I_F = 0.20.}$$

Index of Functionality for the Fiat 640

1. Rotary Switches (Sr)

- Sr1 = Proportion of Rotary Switches having a Length between 25 and 76 mm (1–4 in): **Sr1 = 0/1= 0.**
- Sr2 = Proportion of Rotary Switches having a Width up to 25 mm (1 in): **Sr2 = 0/1= 0.**
- Sr3 = Proportion of Rotary Switches having a Height between 12 and 75 mm (0.5–3 in): **Sr3 = 0/1= 0.**
- Sr4 = Proportion of Rotary Switches having a minimum Separation of 25 mm (1 in): **Sr4 = 0/1= 0.**
- F_{Sr} = Relative frequency of use for rotary switches: $\mathbf{F_{Sr} = 0.12.}$

$$FSr \cdot Sr = FSr \cdot (Sr1 + Sr2 + Sr3 + Sr4)/4$$

2. Push Buttons (Bp)

- Bp1 = Proportion of Push Buttons having a Diameter between 12 and 25 mm (0.5–1 in): **Bp1 = 0/1= 0.**
- Bp2 = Proportion of Push Buttons having a minimum Separation of 50 mm (2 in): **Bp2 = 0/1= 0.**
- F_{Bp} = Relative frequency of use for push buttons: $\mathbf{F_{Bp} = 0.06.}$

$$FBp \cdot Bp = FBp \cdot (Bp1 + Bp2)/2$$

3. Hand–Levers (L)

- L1 = Proportion of Hand–Levers that require a maximum Activation Force of 16 kg (35 lbf): **L1 = 3/6= 0.5.**
- L2 = Proportion of Hand–Levers having a maximum Displacement of 355 mm (14 in): **L2 = 2/6= 0.33.**
- L3 = Proportion of Hand–Levers having a minimum Separation of 100 mm (4 in): **L3 = 1/6= 0.16.**

- L4 = Proportion of Hand–Levers that are located between 570 to 660 mm (22.4 to 26 in) covering a 90° envelope in front of the Seat Reference Point: **L4 = 3/6= 0.5.**
- FL = Relative frequency of use for hand–levers: **FL = 0.81.**

$$FL \cdot L = FL \cdot (L1 + L2 + L3 + L4)/4$$

4. Steering Wheel (Sw)

- Sw1 = If the Diameter is between 400 and 510 mm (15.7–20 in) then Sw1 = 1.
  - **Sw1 = 0.3.**
- Sw2 = If the Rim Thickness is between 19 and 32 mm (0.75–1.25 in) then Sw2 = 1.
  - **Sw2 = 0.3.**
- Sw3 = Proportion of any Hand–Levers located on steering wheel column that have a maximum vertical distance from the steering wheel to their top of 63.5 mm (2.5 in): **Sw3 = 0/1= 0.**
- Sw4 = If the Angle to the horizontal plane is between 40 and 60 degrees then Sw4 = 1.
  - **Sw4 = 0.3.**

$$Sw = (Sw1 + Sw2 + Sw3 + Sw4)/4$$

5. Control Labeling (Lc)

- Lc1 = Proportion of controls having an associated title e.g. a label (*above the controls*) or indication *(e.g. icon, symbol)*: **Lc1 = 2/9= 0.22.**
- Lc2 = Colour – coding: If no more than four colours are used that are well spaced in chroma then Lc2 = 1.

  Lc2 = Colour – coding: Number of colours that are used: *1*, therefore **Lc2 = 1.**

$$Lc = (Lc1 + Lc2)/2$$

6. Functional Reach (Fr)

- Proportion of controls present within a radius of 750 mm (29.5 in) covering a 180° envelope in front of the operator: **Fr = 4/9= 0.44.**

7. Suitability of Controls (Sc)

- Proportion of controls where mode of action is appropriate to function: **Sc = 4/9= 0.44.**

8. Placement of Controls (Pc)

- Proportion of controls present on the right hand side of the operator: **Pc = 2/9= 0.22.**

Calculations

$$I_F = \frac{(F_{Sr} \cdot Sr)+(F_{St} \cdot St)+(F_S \cdot S)+(F_{Kb} \cdot Kb)+(F_{Bp} \cdot Bp)+(F_L \cdot L)+(Ea) \cdot [(0.6 \cdot Pc)+(0.48 \cdot Sc)+(0.5 \cdot Fr)+(0.42 \cdot Lc)]+Sw+Mc}{\sum^{n} F + 4}$$

- Rotary Switches = Sr = (Sr1 + Sr2 + Sr3 + Sr4)/4
  - F_{Sr} = relative frequency of use for rotary switches = 0.12.
  - Sr = (0+0+0+0)/4 = 0.
- Push Buttons = Bp = (Bp1 + Bp2)/2
  - F_{Bp} = relative frequency of use for push buttons = 0.06.
  - Bp = (0+0)/2= 0.
- Hand–Levers = L = (L1 + L2 + L3 + L4)/4
  - F_L = relative frequency of use for hand–levers = 0.81.
  - L = (0.5+0.33+0.16+0.5)/4= 1.49/4= 0.37.
- Steering Wheel = Sw = (Sw1 + Sw2 + Sw3 + Sw4)/4
  - Sw = (0.3+0.3+0+0.3)/4= 0.9/4= 0.22.
- Placement of Controls = Pc
  - Pc = 0.22.
- Suitability of Controls = Sc
  - Sc = 0.44.

- Functional Reach = Fr
  - Fr = 0.44.
- Control Labeling = Lc = (Lc1 + Lc2)/2
  - Lc = (0.22+1)/2= 1.22/2= 0.61.
- Ea = Ergonomic factors average = [(Pc+Sc+Fr+Lc)/4] = 0.42.
- n = 3 = Number of control types (maximum value n = 6, excluding Sw and Mc)

$$I_F = \frac{(0.12\cdot 0)+(0.06\cdot 0)+(0.81\cdot 0.37)+(0.42)\cdot[(0.6\cdot 0.22)+(0.48\cdot 0.44)+(0.5\cdot 0.44)+(0.42\cdot 0.61)]+(0.22)}{(0.12+0.06+0.81)+(4)}$$

$$I_F = \frac{(0.29)+(0.42)\cdot[0.81]+(0.22)}{(0.99)+(4)}$$

I_F= 0.17.

Index of Functionality for the Steyr 650

1. Push Buttons (Bp)

- Bp1 = Proportion of Push Buttons having a Diameter between 12 and 25 mm (0.5–1 in): **Bp1 = 0/2= 0.**
- Bp2 = Proportion of Push Buttons having a minimum Separation of 50 mm (2 in): **Bp2 = 2/2= 1.**
- F_{Bp} = Relative frequency of use for push buttons: **F_{Bp} = 0.33.**

$$FBp \cdot Bp = FBp \cdot (Bp1 + Bp2)/2$$

2. Hand–Levers (L)

- L1 = Proportion of Hand–Levers that require a maximum Activation Force of 16 kg (35 lbf): **L1 = 2/6= 0.33.**
- L2 = Proportion of Hand–Levers having a maximum Displacement of 355 mm (14 in): **L2 = 1/6= 0.16.**
- L3 = Proportion of Hand–Levers having a minimum Separation of 100 mm (4 in): **L3 = 1/6= 0.16.**
- L4 = Proportion of Hand–Levers that are located between 570 to 660 mm (22.4 to 26 in) covering a 90° envelope in front of the Seat Reference Point: **L4 = 0/6= 0.**
- F_L = Relative frequency of use for hand–levers: **F_L = 0.66.**

$$FL \cdot L = FL \cdot (L1 + L2 + L3 + L4)/4$$

3. Steering Wheel (Sw)

- Sw1 = If the Diameter is between 400 and 510 mm (15.7–20 in) then Sw1 = 1.
  - **Sw1 = 0.3.**
- Sw2 = If the Rim Thickness is between 19 and 32 mm (0.75–1.25 in) then Sw2 = 1.
  - **Sw2 = 0.3.**
- Sw3 = Proportion of any Hand–Levers located on steering wheel column that have a maximum vertical distance from the steering wheel to their top of 63.5 mm (2.5 in): **Sw3 = 0/1= 0.**

- Sw4 = If the Angle to the horizontal plane is between 40 and 60 degrees then Sw4 = 1.
    - **Sw4 = 0.3.**

$$Sw = (Sw1 + Sw2 + Sw3 + Sw4)/4$$

4. Control Labeling (Lc)

- Lc1 = Proportion of controls having an associated title e.g. a label (*above the controls*) or indication *(e.g. icon, symbol)*: **Lc1 = 2/9= 0.22.**
- Lc2 = Colour – coding: If no more than four colours are used that are well spaced in chroma then Lc2 = 1.

  Lc2 = Colour – coding: Number of colours that are used: *2*, therefore **Lc2 = 1.**

$$Lc = (Lc1 + Lc2)/2$$

5. Functional Reach (Fr)

- Proportion of controls present within a radius of 750 mm (29.5 in) covering a 180° envelope in front of the operator: **Fr = 4/9= 0.44.**

6. Suitability of Controls (Sc)

- Proportion of controls where mode of action is appropriate to function: **Sc = 3/9= 0.33.**

7. Placement of Controls (Pc)

- Proportion of controls present on the right hand side of the operator: **Pc = 2/9= 0.22.**

Calculations

$$I_F = \frac{(F_{Sr}\cdot Sr)+(F_{St}\cdot St)+(F_S\cdot S)+(F_{Kb}\cdot Kb)+(F_{Bp}\cdot Bp)+(F_L\cdot L)+(Ea)\cdot[(0.6\cdot Pc)+(0.48\cdot Sc)+(0.5\cdot Fr)+(0.42\cdot Lc)]+Sw+Mc}{\sum^{n} F+4}$$

- Push Buttons = Bp = (Bp1 + Bp2)/2
  - F_{Bp} = relative frequency of use for push buttons = 0.33.
  - Bp = (0+1)/2= 1/2= 0.50.
- Hand–Levers = L = (L1 + L2 + L3 + L4)/4
  - F_L = relative frequency of use for hand–levers = 0.66.
  - L = (0.33+0.16+0.16+0)/4= 0.65/4= 0.16.
- Steering Wheel = Sw = (Sw1 + Sw2 + Sw3 + Sw4)/4
  - Sw = (0.3+0.3+0+0.3)/4= 0.9/4= 0.22.
- Placement of Controls = Pc
  - Pc = 0.22.
- Suitability of Controls = Sc
  - Sc = 0.33.
- Functional Reach = Fr
  - Fr = 0.44.
- Control Labeling = Lc = (Lc1 + Lc2)/2
  - Lc = (0.22+1)/2 = 1.22/2= 0.61.
- Ea = Ergonomic factors average = [(Pc+Sc+Fr+Lc)/4] = 0.4.
- n = 2 = Number of control types (maximum value n = 6, excluding Sw and Mc)

$$I_F = \frac{(0.33\cdot 0.5)+(0.66\cdot 0.16)+(0.4)\cdot[(0.6\cdot 0.22)+(0.48\cdot 0.33)+(0.5\cdot 0.44)+(0.42\cdot 0.61)]+(0.22)}{(0.33+0.66)+(4)}$$

$$I_F = \frac{(0.16)+(0.10)+(0.4)\cdot[0.75]+(0.22)}{(0.99)+(4)}$$

$$I_F = \frac{(0.26)+(0.4)\cdot[0.75]+(0.22)}{(4.99)}$$

$$\mathbf{I_F = 0.15.}$$

Index of Functionality for the New Holland S 230

1. Push Buttons (Bp)

- Bp1 = Proportion of Push Buttons having a Diameter between 12 and 25 mm (0.5–1 in): **Bp1 = 0/1= 0.**
- Bp2 = Proportion of Push Buttons having a minimum Separation of 50 mm (2 in): **Bp2 = 0/1= 0.**
- F_{Bp} = Relative frequency of use for push buttons: **F_{Bp} = 0.07.**

$$FBp \cdot Bp = FBp \cdot (Bp1 + Bp2)/2$$

2. Knobs (Kb)

- Kb1 = Proportion of Knobs having a Height between 12 and 25 mm (0.5–1 in): **Kb1 = 0/3= 0.**
- Kb2 = Proportion of Knobs having a Diameter between 12 and 100 mm (0.5–4 in): **Kb2 = 0/3= 0.**
- Kb3 = Proportion of Knobs having a minimum Separation of 50 mm (2 in): **Kb3 = 2/3= 0.66.**
- F_{Kb} = Relative frequency of use for knobs: **F_{Kb} = 0.21.**

$$FKb \cdot Kb = FKb \cdot (Kb1 + Kb2 + Kb3)/3$$

3. Hand–Levers (L)

- L1 = Proportion of Hand–Levers that require a maximum Activation Force of 16 kg (35 lbf): **L1 = 2/7= 0.28.**
- L2 = Proportion of Hand–Levers having a maximum Displacement of 355 mm (14 in): **L2 = 2/7= 0.28.**
- L3 = Proportion of Hand–Levers having a minimum Separation of 100 mm (4 in): **L3 = 1/7= 0.14.**
- L4 = Proportion of Hand–Levers that are located between 570 to 660 mm (22.4 to 26 in) covering a 90° envelope in front of the Seat Reference Point: **L4 = 2/7= 0.28.**
- F_L = Relative frequency of use for hand–levers: **F_L = 0.71.**

$$FL \cdot L = FL \cdot (L1 + L2 + L3 + L4)/4$$

4. Steering Wheel (Sw)

- Sw1 = If the Diameter is between 400 and 510 mm (15.7–20 in) then Sw1 = 1.
  - **Sw1 = 0.3.**
- Sw2 = If the Rim Thickness is between 19 and 32 mm (0.75–1.25 in) then Sw2 = 1.
  - **Sw2 = 0.3.**
- Sw3 = Proportion of any Hand–Levers located on steering wheel column that have a maximum vertical distance from the steering wheel to their top of 63.5 mm (2.5 in): **Sw3 = 0/1= 0.**
- Sw4 = If the Angle to the horizontal plane is between 40 and 60 degrees then Sw4 = 1.
  - **Sw4 = 0.3.**

$$Sw = (Sw1 + Sw2 + Sw3 + Sw4)/4$$

5. Control Labeling (Lc)

- Lc1 = Proportion of controls having an associated title e.g. a label (*above the controls*) or indication *(e.g. icon, symbol)*: **Lc1 = 4/12= 0.33.**
- Lc2 = Colour – coding: If no more than four colours are used that are well spaced in chroma then Lc2 = 1.

  Lc2 = Colour – coding: Number of colours that are used: *3*, therefore **Lc2 = 1.**

$$Lc = (Lc1 + Lc2)/2$$

6. Functional Reach (Fr)

- Proportion of controls present within a radius of 750 mm (29.5 in) covering a 180° envelope in front of the operator: **Fr = 5/12= 0.41.**

7. Suitability of Controls (Sc)

- Proportion of controls where mode of action is appropriate to function: **Sc = 5/12= 0.41.**

8. Placement of Controls (Pc)

- Proportion of controls present on the right hand side of the operator:

  Pc = 2/12= 0.16.

Calculations

$$I_F = \frac{(F_{Sr}\cdot Sr)+(F_{St}\cdot St)+(F_S\cdot S)+(F_{Kb}\cdot Kb)+(F_{Bp}\cdot Bp)+(F_L\cdot L)+(Ea)\cdot[(0.6\cdot Pc)+(0.48\cdot Sc)+(0.5\cdot Fr)+(0.42\cdot Lc)]+Sw+Mc}{\sum^{n} F+4}$$

- Knobs = Kb = (Kb1 + Kb2 + Kb3)/3
  - F_{Kb} = relative frequency of use for knobs = 0.21.
  - Kb = (0+0+0.66)/3= 0.66/3= 0.22.
- Push Buttons = Bp = (Bp1 + Bp2)/2
  - F_{Bp} = relative frequency of use for push buttons = 0.07.
  - Bp = (0+0)/2= 0.
- Hand–Levers = L = (L1 + L2 + L3 + L4)/4
  - F_L = relative frequency of use for hand–levers= 0.71.
  - L = (0.28+0.28+0.14+0.28)/4= 0.98/4= 0.24.
- Steering Wheel = Sw = (Sw1 + Sw2 + Sw3 + Sw4)/4
  - Sw = (0.3+0.3+0+0.3)/4= 0.9/4= 0.22.
- Placement of Controls = Pc
  - Pc = 0.16.
- Suitability of Controls = Sc
  - Sc = 0.41.
- Functional Reach = Fr
  - Fr = 0.41.
- Control Labeling = Lc = (Lc1 + Lc2)/2
  - Lc = (0.33+1)/2= 1.33/2= 0.66.
- Ea = Ergonomic factors average = [(Pc+Sc+Fr+Lc)/4] = 0.41.
- n = 3 = Number of control types (maximum value n = 6, excluding Sw and Mc)

$$I_F = \frac{(0.21 \cdot 0.22)+(0.07 \cdot 0)+(0.71 \cdot 0.24)+(0.41) \cdot [(0.6 \cdot 0.16)+(0.48 \cdot 0.41)+(0.5 \cdot 0.41)+(0.42 \cdot 0.66)]+(0.22)}{(0.21+0.07+0.71) + (4)}$$

$$I_F = \frac{(0.046)+(0.17)+(0.41) \cdot [0.75]+(0.22)}{(0.99) + (4)}$$

$$I_F = \frac{(0.21)+(0.41) \cdot [0.75]+(0.22)}{(4.99)}$$

$$\mathbf{I_F = 0.14.}$$

Appendix B

Data Collection Sheets

Data Collection Sheet for John Deere 8220

Control	Type	Length (mm)	Width (mm)	Height (mm)	Sep/on (mm)	Arm Length	Diameter (mm)	Activation Force (kg)	Dis/nt (mm)	L4 Factor H. Lever	Rim Th/ss	Sw3 Factor	Angle (degrees)
Steering Wheel	Steering Wheel	N/A	N/A	N/A	N/A	N/A	400	N/A	N/A	N/A	30	1/4	45°
PTO RPM	Button	N/A	N/A	N/A	8	N/A	25	N/A	N/A	N/A	N/A	N/A	N/A
Hydraulic Engagement	Button	N/A	N/A	N/A	8	N/A	25	N/A	N/A	N/A	N/A	N/A	N/A
3 – Point Hitch	Button	N/A	N/A	N/A	8	N/A	25	N/A	N/A	N/A	N/A	N/A	N/A
PTO Engagement	Button	N/A	N/A	N/A	50	N/A	24	N/A	N/A	N/A	N/A	N/A	N/A
Throttle	Toggle Switch	N/A	N/A	N/A	30	18	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Gearshift – Reverser	Hand – Lever	N/A	N/A	N/A	83	N/A	N/A	1.5	40	1/2	N/A	N/A	N/A
Differential Lock	Button	N/A	N/A	N/A	23	N/A	25	N/A	N/A	N/A	N/A	N/A	N/A
Air Conditioning	Knob	N/A	N/A	15	20	N/A	29	N/A	N/A	N/A	N/A	N/A	N/A
Radio Channel Selector 1	Button	N/A	N/A	N/A	3	N/A	10	N/A	N/A	N/A	N/A	N/A	N/A
Radio Channel Selector 2	Button	N/A	N/A	N/A	3	N/A	10	N/A	N/A	N/A	N/A	N/A	N/A
Radio Volume	Knob	N/A	N/A	15	50	N/A	20	N/A	N/A	N/A	N/A	N/A	N/A
Windshield Wipers	Knob	N/A	N/A	15	38	N/A	35	N/A	N/A	N/A	N/A	N/A	N/A
Windshield Defroster	Knob	N/A	N/A	15	20	N/A	29	N/A	N/A	N/A	N/A	N/A	N/A
Windshield Washer	Rocker Switch	15	15	N/A	30	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Headlights	Knob	N/A	N/A	15	38	N/A	35	N/A	N/A	N/A	N/A	N/A	N/A
Turn Signal – Horn	Hand – Lever	N/A	N/A	N/A	80	N/A	N/A	0.75	70	1/2	N/A	N/A	N/A
Hazard Lights	Rocker Switch	15	15	N/A	30	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Hydraulic Control 1	Rocker Switch	22	19	N/A	33	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Hydraulic Control 2	Rocker Switch	22	19	N/A	33	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Hydraulic Control 3	Rocker Switch	22	19	N/A	33	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Hydraulic Control 4	Rocker Switch	22	19	N/A	33	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Hydraulic Control 5	Toggle Switch	N/A	N/A	N/A	52	25	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Hydraulic Control 6	Rocker Switch	22	19	N/A	120	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Hydraulic Control 7	Knob	N/A	N/A	15	71	N/A	21	N/A	N/A	N/A	N/A	N/A	N/A
Hydraulic Control 8	Knob	N/A	N/A	15	35	N/A	21	N/A	N/A	N/A	N/A	N/A	N/A
Hydraulic Control 9	Knob	N/A	N/A	15	35	N/A	21	N/A	N/A	N/A	N/A	N/A	N/A
Fan Speed	Knob	N/A	N/A	15	56	N/A	29	N/A	N/A	N/A	N/A	N/A	N/A
Auto Steer	Rocker Switch	15	15	N/A	30	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Injection Button	Button	N/A	N/A	N/A	230	N/A	19	N/A	N/A	N/A	N/A	N/A	N/A
Height Adjustment	Knob	N/A	N/A	15	80	N/A	21	N/A	N/A	N/A	N/A	N/A	N/A

Operation Button 1	Button	N/A	N/A	N/A	8	N/A	25	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 2	Button	N/A	N/A	N/A	8	N/A	25	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 3	Button	N/A	N/A	N/A	8	N/A	25	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 4	Button	N/A	N/A	N/A	8	N/A	25	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 5	Button	N/A	N/A	N/A	8	N/A	25	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 6	Button	N/A	N/A	N/A	8	N/A	25	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 7	Button	N/A	N/A	N/A	8	N/A	25	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 8	Button	N/A	N/A	N/A	8	N/A	25	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 9	Button	N/A	N/A	N/A	8	N/A	25	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 10	Button	N/A	N/A	N/A	8	N/A	25	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 11	Button	N/A	N/A	N/A	8	N/A	25	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 12	Button	N/A	N/A	N/A	8	N/A	25	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 13	Button	N/A	N/A	N/A	8	N/A	25	N/A	N/A	N/A	N/A	N/A	N/A
Seat Adjustment 1	Rocker Switch	14	18	N/A	48	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Seat Adjustment 2	Rocker Switch	14	18	N/A	48	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Cab Light 1	Rocker Switch	11	12	N/A	50	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Cab Light 2	Rocker Switch	18	18	N/A	50	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Multifunction Hand Controls (Mc)

	YES	NO
➢ Located at the right hand side of the operator	X	

➢ Activation Force (kg) | 1 |

➢ Displacement (mm) | 97 |

	YES	NO
➢ Present of a second, third,.., multifunction hand control		X

Control Labeling (Lc)

- Lc1 = Proportion of controls having an associated title e.g. a label (*above the controls*) or indication *(e.g. icon, symbol)*: *46/49*
  Labels: In case of labels, the height of numerals and letters must be at least 2.5 mm (0.1 in)
  Icons and Symbols: In case of icons and symbols, consideration of the standard icons and symbols will be used based on ANSI/ASAE S304.7
- Lc2 = Colour – coding: Number of colours that are used: *4*

Functional Reach (Fr)

- Proportion of controls present within a radius of 750 mm (29.5 in) covering a 180° envelope in front of the operator: *43/49*

Placement of Controls (Pc)

- Proportion of controls present on the right hand side of the operator: *46/49*

Suitability of Controls (Sc)

- Proportion of controls where mode of action is appropriate to function: *46/49*

John Deere 8220

Total number of control types = 7

Steering Wheel	=	1
Buttons	=	21
Toggle Switches	=	2
Hand – Levers	=	2
Knobs	=	10
Rocker Switches	=	12
Multifunction Control	=	1

Total number of controls 49

- Controls with Red Colour: *Controls related to the functioning of the implement*
  e.g. Hydraulic, PTO, 3–Point hitch.
- Controls with Green Colour: *Controls related to the motion of the tractor*
  e.g. Gearshift, Hand brake, Throttle, Reverser.
- Controls with Amber Colour: *Controls related to the internal environment*
  e.g. Air conditioning, Cigarette lighter, Radio channel selector, Radio volume.
- Controls with Blue Colour: *Controls related to the external environment*
  e.g. Headlights, Turn signal, Windshield wipers, Horn.

Data Collection Sheet for Case IH MX 230

Control	Type	Length (mm)	Width (mm)	Height (mm)	Sep/on (mm)	Arm Length	Diameter (mm)	Activation Force (kg)	Dis/nt (mm)	L4 Factor H. Lever	Rim Th/ss	Sw3 Factor	Angle (degrees)
Steering Wheel	Steering Wheel	N/A	N/A	N/A	N/A	N/A	401	N/A	N/A	N/A	31	1/2	90°
3 – Point Hitch	Rocker Switch	24	20	N/A	10	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
PTO Engagement	Toggle Switch	N/A	N/A	N/A	57	29	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Gearshift – Reverser	Hand – Lever	N/A	N/A	N/A	200	N/A	N/A	1	81	1/2	N/A	N/A	N/A
Differential Lock	Rocker Switch	24	20	N/A	10	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Air Conditioning	Knob	N/A	N/A	7	35	N/A	50	N/A	N/A	N/A	N/A	N/A	N/A
Radio Channel Selector 1	Button	N/A	N/A	N/A	3	N/A	10	N/A	N/A	N/A	N/A	N/A	N/A
Radio Channel Selector 2	Button	N/A	N/A	N/A	3	N/A	10	N/A	N/A	N/A	N/A	N/A	N/A
Radio Volume	Knob	N/A	N/A	11	50	N/A	18	N/A	N/A	N/A	N/A	N/A	N/A
Windshield Wipers	Rocker Switch	24	20	N/A	42	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Windshield Defroster	Rocker Switch	24	20	N/A	45	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Windshield Washer	Knob	N/A	N/A	7	34	N/A	50	N/A	N/A	N/A	N/A	N/A	N/A
Headlights	Rotary Switch	47	11	10	42	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Turn Signal – Horn	Hand – Lever	N/A	N/A	N/A	200	N/A	N/A	0.9	27	1/2	N/A	N/A	N/A
Hazard Lights	Rocker Switch	22	19	N/A	68	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Hydraulic Control 1	Toggle Switch	N/A	N/A	N/A	34	32	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Hydraulic Control 2	Toggle Switch	N/A	N/A	N/A	34	32	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Hydraulic Control 3	Toggle Switch	N/A	N/A	N/A	34	32	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Hydraulic Control 4	Toggle Switch	N/A	N/A	N/A	34	32	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fan Speed	Knob	N/A	N/A	7	35	N/A	50	N/A	N/A	N/A	N/A	N/A	N/A
Auto Steer	Rocker Switch	24	20	N/A	10	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Height Adjustment	Knob	N/A	N/A	18	26	N/A	19	N/A	N/A	N/A	N/A	N/A	N/A

Operation Button 1	Rocker Switch	24	20	N/A	42	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 2	Toggle Switch	N/A	N/A	N/A	51	14	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 3	Toggle Switch	N/A	N/A	N/A	51	14	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 4	Toggle Switch	N/A	N/A	N/A	51	14	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 5	Toggle Switch	N/A	N/A	N/A	51	14	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 6	Rocker Switch	24	20	N/A	10	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 7	Knob	N/A	N/A	19	20	N/A	14	N/A	N/A	N/A	N/A	N/A	N/A
Hydraulic Control 5	Rocker Switch	24	20	N/A	10	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Hydraulic Control 6	Rocker Switch	24	20	N/A	10	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Hydraulic Control 7	Rocker Switch	24	20	N/A	10	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Hydraulic Control 8	Knob	N/A	N/A	19	12	N/A	13	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 8	Rocker Switch	24	20	N/A	145	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 9	Rocker Switch	24	20	N/A	145	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Cab Light 1	Toggle Switch	N/A	N/A	N/A	78	3	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Cab Light 2	Button	N/A	N/A	N/A	87	N/A	15	N/A	N/A	N/A	N/A	N/A	N/A
Seat Heat Switch	Rocker Switch	6	14	N/A	28	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Cigarette Lighter	Button	N/A	N/A	N/A	115	N/A	27	N/A	N/A	N/A	N/A	N/A	N/A

Operation Button 10	Button	N/A	N/A	N/A	4	N/A	16	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 11	Button	N/A	N/A	N/A	4	N/A	16	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 12	Button	N/A	N/A	N/A	4	N/A	16	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 13	Button	N/A	N/A	N/A	4	N/A	16	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 14	Button	N/A	N/A	N/A	4	N/A	16	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 15	Button	N/A	N/A	N/A	4	N/A	16	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 16	Button	N/A	N/A	N/A	4	N/A	16	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 17	Button	N/A	N/A	N/A	4	N/A	16	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 18	Button	N/A	N/A	N/A	4	N/A	16	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 19	Button	N/A	N/A	N/A	4	N/A	16	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 20	Button	N/A	N/A	N/A	4	N/A	16	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 21	Button	N/A	N/A	N/A	4	N/A	16	N/A	N/A	N/A	N/A	N/A	N/A

Multifunction Hand Controls (Mc)

- Located at the right hand side of the operator — YES: X | NO:
- Activation Force (kg): 2
- Displacement (mm): 103
- Present of a second, third,.., multifunction hand control — YES: | NO: X

Control Labeling (Lc)

- Lc1 = Proportion of controls having an associated title e.g. a label (*above the controls*) or indication *(e.g. icon, symbol)*: *50/52*
  Labels: In case of labels, the height of numerals and letters must be at least 2.5 mm (0.1 in)
  Icons and Symbols: In case of icons and symbols, consideration of the standard icons and symbols will be used based on ANSI/ASAE S304.7
- Lc2 = Colour – coding: Number of colours that are used: *3*

Functional Reach (Fr)

- Proportion of controls present within a radius of 750 mm (29.5 in) covering a 180° envelope in front of the operator: *30/52*

Placement of Controls (Pc)

- Proportion of controls present on the right hand side of the operator: *46/52*

Suitability of Controls (Sc)

- Proportion of controls where mode of action is appropriate to function: *49/52*

Case IH MX 230

Total number of control types = 8

✦	Steering Wheel	= 1
✦	Buttons	= 16
✦	Toggle Switches	= 10
✦	Hand – Levers	= 2
✦	Knobs	= 7
✦	Rocker Switches	= 14
✦	Rotary Switch	= 1
✦	Multifunction Control	= 1

Total number of controls 52

- Controls with Red Colour: *Controls related to the functioning of the implement*
  e.g. Hydraulic, PTO, 3–Point hitch.
- Controls with Green Colour: *Controls related to the motion of the tractor*
  e.g. Gearshift, Hand brake, Throttle, Reverser.
- Controls with Amber Colour: *Controls related to the internal environment*
  e.g. Air conditioning, Cigarette lighter, Radio channel selector, Radio volume.
- Controls with Blue Colour: *Controls related to the external environment*
  e.g. Headlights, Turn signal, Windshield wipers, Horn.

Data Collection Sheet for Buhler–Versatile 2210

Control	Type	Length (mm)	Width (mm)	Height (mm)	Sep/on (mm)	Arm Length	Diameter (mm)	Activation Force (kg)	Dis/nt (mm)	L4 Factor H. Lever	Rim Th/ss	Sw3 Factor	Angle (degrees)
Steering Wheel	Steering Wheel	N/A	N/A	N/A	N/A	N/A	387	N/A	N/A	N/A	26	1/2	50°
PTO RPM 1	Button	N/A	N/A	N/A	50	N/A	40	N/A	N/A	N/A	N/A	N/A	N/A
PTO RPM 2	Button	N/A	N/A	N/A	50	N/A	30	N/A	N/A	N/A	N/A	N/A	N/A
PTO RPM 3	Rocker Switch	20	18	N/A	20	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
3 – Point Hitch	Rocker Switch	20	18	N/A	20	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Differential Lock	Rocker Switch	20	18	N/A	20	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Air Conditioning 1	Button	N/A	N/A	N/A	20	N/A	10	N/A	N/A	N/A	N/A	N/A	N/A
Air Conditioning 2	Knob	N/A	N/A	20	22	N/A	45	N/A	N/A	N/A	N/A	N/A	N/A
Windshield Wipers	Knob	N/A	N/A	20	22	N/A	45	N/A	N/A	N/A	N/A	N/A	N/A
Windshield Washer	Knob	N/A	N/A	20	22	N/A	45	N/A	N/A	N/A	N/A	N/A	N/A
Headlights–Turn Signal–Horn 1	Hand – Lever	N/A	N/A	N/A	40	N/A	N/A	0.7	50	4/4	N/A	N/A	N/A
Headlights–Turn Signal – Horn 2	Knob	N/A	N/A	20	22	N/A	45	N/A	N/A	N/A	N/A	N/A	N/A
Hazard Lights	Rocker Switch	20	18	N/A	26	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Hydraulic Control 1	Hand – Lever	N/A	N/A	N/A	50	N/A	N/A	4.2	130	4/4	N/A	N/A	N/A
Hydraulic Control 2	Button	N/A	N/A	N/A	50	N/A	40	N/A	N/A	N/A	N/A	N/A	N/A
Hydraulic Control 3	Rocker Switch	20	18	N/A	20	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Hydraulic Control 4	Knob	N/A	N/A	22	23	N/A	21	N/A	N/A	N/A	N/A	N/A	N/A

Hydraulic Control 5	Knob	N/A	N/A	22	23	N/A	21	N/A	N/A	N/A	N/A	N/A	N/A
Hydraulic Control 6	Knob	N/A	N/A	22	23	N/A	21	N/A	N/A	N/A	N/A	N/A	N/A
Hydraulic Control 7	Rocker Switch	20	18	N/A	20	N/A	N/A	N/A	N/A	N/ A	N/A	N/A	N/A
Fan Speed	Knob	N/A	N/A	20	22	N/A	45	N/A	N/A	N/A	N/A	N/A	N/A
Auto Steer	Rocker Switch	20	18	N/A	20	N/A	N/A	N/A	N/A	N/ A	N/A	N/A	N/A
Injection Button	Button	N/A	N/A	N/A	40	N/A	30	N/A	N/A	N/A	N/A	N/A	N/A
Height Adjustment	Hand – Lever	N/A	N/A	N/A	40	N/A	N/A	1.7	70	4/4	N/A	N/A	N/A
Hydraulic Control 8	Rocker Switch	11	10	N/A	13	N/A	N/A	N/A	N/A	N/ A	N/A	N/A	N/A
Hydraulic Control 9	Rocker Switch	11	10	N/A	13	N/A	N/A	N/A	N/A	N/ A	N/A	N/A	N/A
Hydraulic Control 10	Rocker Switch	11	10	N/A	13	N/A	N/A	N/A	N/A	N/ A	N/A	N/A	N/A
Hydraulic Control 11	Rocker Switch	11	10	N/A	13	N/A	N/A	N/A	N/A	N/ A	N/A	N/A	N/A
Hydraulic Control 12	Toggle Switch	N/A	N/A	N/A	5	28	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Hydraulic Control 13	Toggle Switch	N/A	N/A	N/A	5	28	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Hydraulic Control 14	Toggle Switch	N/A	N/A	N/A	5	28	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Hydraulic Control 15	Toggle Switch	N/A	N/A	N/A	5	28	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Over Ride	Rocker Switch	20	18	N/A	20	N/A	N/A	N/A	N/A	N/ A	N/A	N/A	N/A
Cigarette Lighter	Button	N/A	N/A	N/A	75	N/A	20	N/A	N/A	N/A	N/A	N/A	N/A
Hand Brake	Hand – Lever	N/A	N/A	N/A	300	N/A	N/A	8.7	190	4/4	N/A	N/A	N/A

Operation Button 1	Button	N/A	N/A	N/A	3	N/A	18	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 2	Button	N/A	N/A	N/A	3	N/A	18	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 3	Button	N/A	N/A	N/A	3	N/A	18	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 4	Button	N/A	N/A	N/A	3	N/A	18	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 5	Button	N/A	N/A	N/A	3	N/A	18	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 6	Button	N/A	N/A	N/A	3	N/A	18	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 7	Button	N/A	N/A	N/A	3	N/A	18	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 8	Button	N/A	N/A	N/A	3	N/A	18	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 9	Button	N/A	N/A	N/A	3	N/A	18	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 10	Button	N/A	N/A	N/A	3	N/A	18	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 11	Button	N/A	N/A	N/A	3	N/A	18	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 12	Button	N/A	N/A	N/A	3	N/A	18	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 13	Button	N/A	N/A	N/A	3	N/A	18	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 14	Button	N/A	N/A	N/A	3	N/A	18	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 15	Button	N/A	N/A	N/A	3	N/A	18	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 16	Button	N/A	N/A	N/A	3	N/A	18	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 17	Button	N/A	N/A	N/A	3	N/A	18	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 18	Button	N/A	N/A	N/A	3	N/A	18	N/A	N/A	N/A	N/A	N/A	N/A

Hydraulic Control 16	Rocker Switch	20	18	N/A	24	N/A	N/A	N/A	N/A	N/ A	N/A	N/A	N/A
Hydraulic Control 17	Rocker Switch	20	18	N/A	24	N/A	N/A	N/A	N/A	N/ A	N/A	N/A	N/A
Seat Adjustment	Rocker Switch	12	13	N/A	232	N/A	N/A	N/A	N/A	N/ A	N/A	N/A	N/A

Multifunction Hand Controls (Mc)

	YES	NO
➢ Located at the right hand side of the operator	X	

➢ Activation Force (kg) 1.1

➢ Displacement (mm) 109

	YES	NO
➢ Present of a second, third,.., multifunction hand control		X

Control Labeling (Lc)

- Lc1 = Proportion of controls having an associated title e.g. a label (*above the controls*) or indication *(e.g. icon, symbol)*: *55/57*
  Labels: In case of labels, the height of numerals and letters must be at least 2.5 mm (0.1 in)
  Icons and Symbols: In case of icons and symbols, consideration of the standard icons and symbols will be used based on ANSI/ASAE S304.7
- Lc2 = Colour – coding: Number of colours that are used: *7*

Functional Reach (Fr)

- Proportion of controls present within a radius of 750 mm (29.5 in) covering a 180° envelope in front of the operator: *49/57*

Placement of Controls (Pc)

- Proportion of controls present on the right hand side of the operator: *49/57*

Suitability of Controls (Sc)

- Proportion of controls where mode of action is appropriate to function: *56/57*

Buhler–Versatile 2210

Total number of control types = 7

- Steering Wheel = 1
- Buttons = 24
- Toggle Switches = 4
- Hand–Levers = 4
- Knobs = 8
- Rocker Switches = 15
- Multifunction Control = 1

Total number of controls 57

- Controls with Red Colour: *Controls related to the functioning of the implement*
  e.g. Hydraulic, PTO, 3–Point hitch.
- Controls with Green Colour: *Controls related to the motion of the tractor*
  e.g. Gearshift, Hand brake, Throttle, Reverser.
- Controls with Amber Colour: *Controls related to the internal environment*
  e.g. Air conditioning, Cigarette lighter, Radio channel selector, Radio volume.
- Controls with Blue Colour: *Controls related to the external environment*
  e.g. Headlights, Turn signal, Windshield wipers, Horn.

Data Collection Sheet for New Holland TG 285

Control	Type	Length (mm)	Width (mm)	Height (mm)	Sep/on (mm)	Arm Length	Diameter (mm)	Activation Force (kg)	Dis/nt (mm)	L4 Factor H. Lever	Rim Th/ss	Sw3 Factor	Angle (degrees)
Steering Wheel	Steering Wheel	N/A	N/A	N/A	N/A	N/A	402	N/A	N/A	N/A	32	1/1	90°
PTO RPM	Rocker Switch	24	20	N/A	10	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
3 – Point Hitch	Rocker Switch	24	20	N/A	10	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
PTO Engagement	Toggle Switch	N/A	N/A	N/A	57	28	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Throttle	Hand – Lever	N/A	N/A	N/A	25	N/A	N/A	1.1	105	1/2	N/A	N/A	N/A
Differential Lock	Rocker Switch	24	20	N/A	10	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Air Conditioning	Knob	N/A	N/A	7	35	N/A	50	N/A	N/A	N/A	N/A	N/A	N/A
Radio Channel Selector 1	Button	N/A	N/A	N/A	3	N/A	10	N/A	N/A	N/A	N/A	N/A	N/A
Radio Channel Selector 2	Button	N/A	N/A	N/A	3	N/A	10	N/A	N/A	N/A	N/A	N/A	N/A
Radio Volume	Knob	N/A	N/A	11	50	N/A	18	N/A	N/A	N/A	N/A	N/A	N/A
Windshield Wipers	Knob	N/A	N/A	7	34	N/A	50	N/A	N/A	N/A	N/A	N/A	N/A
Windshield Defroster	Knob	N/A	N/A	7	34	N/A	50	N/A	N/A	N/A	N/A	N/A	N/A
Windshield Washer	Rocker Switch	24	20	N/A	42	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Headlights	Rotary Switch	47	11	10	42	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Turn Signal – Horn	Hand – Lever	N/A	N/A	N/A	200	N/A	N/A	1.2	27	1/2	N/A	N/A	N/A
Hazard Lights	Rocker Switch	22	19	N/A	68	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Hydraulic Control 1	Toggle Switch	N/A	N/A	N/A	20	31	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Hydraulic Control 2	Toggle Switch	N/A	N/A	N/A	20	31	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Hydraulic Control 3	Toggle Switch	N/A	N/A	N/A	20	31	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Hydraulic Control 4	Toggle Switch	N/A	N/A	N/A	20	31	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fan Speed	Knob	N/A	N/A	7	35	N/A	50	N/A	N/A	N/A	N/A	N/A	N/A
Auto Steer	Rocker Switch	24	20	N/A	10	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Height Adjustment	Knob	N/A	N/A	18	26	N/A	19	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 1	Rocker Switch	24	20	N/A	42	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 2	Toggle Switch	N/A	N/A	N/A	51	14	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 3	Toggle Switch	N/A	N/A	N/A	51	14	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 4	Toggle Switch	N/A	N/A	N/A	51	14	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 5	Toggle Switch	N/A	N/A	N/A	51	14	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 6	Rocker Switch	24	20	N/A	10	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 7	Knob	N/A	N/A	19	20	N/A	14	N/A	N/A	N/A	N/A	N/A	N/A
Hydraulic Control 5	Rocker Switch	24	20	N/A	10	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Hydraulic Control 6	Rocker Switch	24	20	N/A	10	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Hydraulic Control 7	Rocker Switch	24	20	N/A	10	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 8	Rocker Switch	24	20	N/A	145	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 9	Rocker Switch	24	20	N/A	145	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Cab Light 1	Toggle Switch	N/A	N/A	N/A	78	3	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Cab Light 2	Button	N/A	N/A	N/A	87	N/A	15	N/A	N/A	N/A	N/A	N/A	N/A

Seat Adjustment 1	Rocker Switch	12	15	N/A	140	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Seat Heat Switch	Rocker Switch	6	14	N/A	140	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Cigarette Lighter	Button	N/A	N/A	N/A	115	N/A	27	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 10	Button	N/A	N/A	N/A	4	N/A	16	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 11	Button	N/A	N/A	N/A	4	N/A	16	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 12	Button	N/A	N/A	N/A	4	N/A	16	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 13	Button	N/A	N/A	N/A	4	N/A	16	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 14	Button	N/A	N/A	N/A	4	N/A	16	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 15	Button	N/A	N/A	N/A	4	N/A	16	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 16	Button	N/A	N/A	N/A	4	N/A	16	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 17	Button	N/A	N/A	N/A	4	N/A	16	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 18	Button	N/A	N/A	N/A	4	N/A	16	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 19	Button	N/A	N/A	N/A	4	N/A	16	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 20	Button	N/A	N/A	N/A	4	N/A	16	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 21	Button	N/A	N/A	N/A	4	N/A	16	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 22	Button	N/A	N/A	N/A	4	N/A	16	N/A	N/A	N/A	N/A	N/A	N/A

Multifunction Hand Controls (Mc)

	YES	NO
➢ Located at the right hand side of the operator	X	

- ➢ Activation Force (kg): 1.4
- ➢ Displacement (mm): 130

	YES	NO
➢ Present of a second, third,.., multifunction hand control		X

Control Labeling (Lc)

- ➢ Lc1 = Proportion of controls having an associated title e.g. a label (*above the controls*) or indication *(e.g. icon, symbol)*: *52/54*
  Labels: In case of labels, the height of numerals and letters must be at least 2.5 mm (0.1 in)
  Icons and Symbols: In case of icons and symbols, consideration of the standard icons and symbols will be used based on ANSI/ASAE S304.7
- ➢ Lc2 = Colour – coding: Number of colours that are used: *6*

Functional Reach (Fr)

- ➢ Proportion of controls present within a radius of 750 mm (29.5 in) covering a 180° envelope in front of the operator: *31/54*

Placement of Controls (Pc)

- ➢ Proportion of controls present on the right hand side of the operator: *49/54*

Suitability of Controls (Sc)

- ➢ Proportion of controls where mode of action is appropriate to function: *51/54*

New Holland TG 285

Total number of control types = 8

Steering Wheel	=	1
Buttons	=	17
Toggle Switches	=	10
Hand – Levers	=	2
Knobs	=	7
Rocker Switches	=	15
Rotary Switch	=	1
Multifunction Control	=	1

Total number of controls 54

- Controls with Red Colour: *Controls related to the functioning of the implement e.g. Hydraulic, PTO, 3–Point hitch.*
- Controls with Green Colour: *Controls related to the motion of the tractor e.g. Gearshift, Hand brake, Throttle, Reverser.*
- Controls with Amber Colour: *Controls related to the internal environment e.g. Air conditioning, Cigarette lighter, Radio channel selector, Radio volume.*
- Controls with Blue Colour: *Controls related to the external environment e.g. Headlights, Turn signal, Windshield wipers, Horn.*

Data Collection Sheet for Fendt 920 Vario

Control	Type	Length (mm)	Width (mm)	Height (mm)	Sep/on (mm)	Arm Length	Diameter (mm)	Activation Force (kg)	Dis/nt (mm)	L4 Factor H. Lever	Rim Th/ss	Sw3 Factor	Angle (degrees)
Steering Wheel	Steering Wheel	N/A	N/A	N/A	N/A	N/A	407	N/A	N/A	N/A	29	0/2	55°
PTO RPM 1	Button	N/A	N/A	N/A	5	N/A	23	N/A	N/A	N/A	N/A	N/A	N/A
PTO RPM 2	Button	N/A	N/A	N/A	5	N/A	23	N/A	N/A	N/A	N/A	N/A	N/A
PTO RPM 3	Button	N/A	N/A	N/A	5	N/A	23	N/A	N/A	N/A	N/A	N/A	N/A
3 – Point Hitch 1	Button	N/A	N/A	N/A	7	N/A	17	N/A	N/A	N/A	N/A	N/A	N/A
3 – Point Hitch 2	Button	N/A	N/A	N/A	7	N/A	17	N/A	N/A	N/A	N/A	N/A	N/A
3 – Point Hitch 3	Button	N/A	N/A	N/A	7	N/A	17	N/A	N/A	N/A	N/A	N/A	N/A
PTO Engagement	Button	N/A	N/A	N/A	5	N/A	23	N/A	N/A	N/A	N/A	N/A	N/A
Gearshift – Reverser	Hand – Lever	N/A	N/A	N/A	52	N/A	N/A	1.2	66	1/4	N/A	N/A	N/A
Differential Lock	Rocker Switch	14	12	N/A	40	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Air Conditioning	Knob	N/A	N/A	12	25	N/A	45	N/A	N/A	N/A	N/A	N/A	N/A
Radio Channel Selector 1	Button	N/A	N/A	N/A	12	N/A	8	N/A	N/A	N/A	N/A	N/A	N/A
Radio Channel Selector 2	Button	N/A	N/A	N/A	12	N/A	8	N/A	N/A	N/A	N/A	N/A	N/A
Radio Volume	Knob	N/A	N/A	3	50	N/A	25	N/A	N/A	N/A	N/A	N/A	N/A
Windshield Wipers	Rocker Switch	18	18	N/A	12	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Windshield Defroster	Knob	N/A	N/A	20	20	N/A	51	N/A	N/A	N/A	N/A	N/A	N/A
Windshield Washer	Rocker Switch	15	15	N/A	30	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Headlights	Button	N/A	N/A	N/A	23	N/A	23	N/A	N/A	N/A	N/A	N/A	N/A
Turn Signal – Horn	Hand – Lever	N/A	N/A	N/A	52	N/A	N/A	1.2	40	1/4	N/A	N/A	N/A
Hazard Lights 1	Button	N/A	N/A	N/A	23	N/A	23	N/A	N/A	N/A	N/A	N/A	N/A
Hazard Lights 2	Button	N/A	N/A	N/A	23	N/A	23	N/A	N/A	N/A	N/A	N/A	N/A
Hydraulic Control 1	Button	N/A	N/A	N/A	5	N/A	23	N/A	N/A	N/A	N/A	N/A	N/A
Hydraulic Control 2	Button	N/A	N/A	N/A	5	N/A	23	N/A	N/A	N/A	N/A	N/A	N/A
Hydraulic Control 3	Button	N/A	N/A	N/A	5	N/A	23	N/A	N/A	N/A	N/A	N/A	N/A
Hydraulic Control 4	Button	N/A	N/A	N/A	5	N/A	23	N/A	N/A	N/A	N/A	N/A	N/A
Hydraulic Control 5	Button	N/A	N/A	N/A	5	N/A	23	N/A	N/A	N/A	N/A	N/A	N/A
Hydraulic Control 6	Button	N/A	N/A	N/A	5	N/A	23	N/A	N/A	N/A	N/A	N/A	N/A
Hydraulic Control 7	Button	N/A	N/A	N/A	5	N/A	23	N/A	N/A	N/A	N/A	N/A	N/A
Hydraulic Control 8	Button	N/A	N/A	N/A	5	N/A	23	N/A	N/A	N/A	N/A	N/A	N/A
Hydraulic Control 9	Button	N/A	N/A	N/A	5	N/A	23	N/A	N/A	N/A	N/A	N/A	N/A
Fan Speed 1	Knob	N/A	N/A	12	69	N/A	50	N/A	N/A	N/A	N/A	N/A	N/A
Fan Speed 2	Knob	N/A	N/A	12	69	N/A	50	N/A	N/A	N/A	N/A	N/A	N/A
Injection Button	Button	N/A	N/A	N/A	5	N/A	23	N/A	N/A	N/A	N/A	N/A	N/A
Height Adjustment	Hand – Lever	N/A	N/A	N/A	70	N/A	N/A	0.3	50	1/4	N/A	N/A	N/A

Operation Button 1	Button	N/A	N/A	N/A	5	N/A	23	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 2	Button	N/A	N/A	N/A	5	N/A	23	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 3	Button	N/A	N/A	N/A	5	N/A	23	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 4	Button	N/A	N/A	N/A	5	N/A	23	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 5	Button	N/A	N/A	N/A	5	N/A	23	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 6	Button	N/A	N/A	N/A	5	N/A	23	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 7	Button	N/A	N/A	N/A	5	N/A	23	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 8	Button	N/A	N/A	N/A	5	N/A	23	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 9	Button	N/A	N/A	N/A	5	N/A	23	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 10	Button	N/A	N/A	N/A	5	N/A	23	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 11	Button	N/A	N/A	N/A	5	N/A	23	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 12	Button	N/A	N/A	N/A	5	N/A	23	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 13	Button	N/A	N/A	N/A	5	N/A	23	N/A	N/A	N/A	N/A	N/A	N/A

Operation Button 14	Button	N/A	N/A	N/A	5	N/A	23	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 15	Button	N/A	N/A	N/A	5	N/A	23	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 16	Button	N/A	N/A	N/A	5	N/A	23	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 17	Button	N/A	N/A	N/A	5	N/A	23	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 18	Button	N/A	N/A	N/A	5	N/A	23	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 19	Button	N/A	N/A	N/A	5	N/A	23	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 20	Button	N/A	N/A	N/A	5	N/A	23	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 21	Button	N/A	N/A	N/A	5	N/A	23	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 22	Button	N/A	N/A	N/A	5	N/A	23	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 23	Button	N/A	N/A	N/A	5	N/A	23	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 24	Button	N/A	N/A	N/A	5	N/A	23	N/A	N/A	N/A	N/A	N/A	N/A

Seat Adjustment 1	Rocker Switch	15	15	N/A	60	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Cab Light 1	Button	N/A	N/A	N/A	57	N/A	8	N/A	N/A	N/A	N/A	N/A	N/A
Cab Light 2	Rocker Switch	12	5	N/A	83	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Hydraulic Control 10	Button	N/A	N/A	N/A	5	N/A	23	N/A	N/A	N/A	N/A	N/A	N/A
Hydraulic Control 11	Button	N/A	N/A	N/A	17	N/A	16	N/A	N/A	N/A	N/A	N/A	N/A
Hydraulic Control 12	Button	N/A	N/A	N/A	17	N/A	16	N/A	N/A	N/A	N/A	N/A	N/A
Hydraulic Control 13	Button	N/A	N/A	N/A	24	N/A	18	N/A	N/A	N/A	N/A	N/A	N/A
Hydraulic Control 14	Button	N/A	N/A	N/A	24	N/A	18	N/A	N/A	N/A	N/A	N/A	N/A
Operation Knob 1	Knob	N/A	N/A	12	69	N/A	50	N/A	N/A	N/A	N/A	N/A	N/A
Operation Rocker Switch	Rocker Switch	20	18	N/A	30	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Hand Brake	Hand – Lever	N/A	N/A	N/A	340	N/A	N/A	2.5	73	1/4	N/A	N/A	N/A
Operation Knob 2	Knob	N/A	N/A	19	20	N/A	18	N/A	N/A	N/A	N/A	N/A	N/A
Operation Knob 3	Knob	N/A	N/A	19	20	N/A	18	N/A	N/A	N/A	N/A	N/A	N/A
Operation Knob 4	Knob	N/A	N/A	19	20	N/A	18	N/A	N/A	N/A	N/A	N/A	N/A

Multifunction Hand Controls (Mc)

	YES	NO
➢ Located at the right hand side of the operator	X	

➢ Activation Force (kg): 0.5

➢ Displacement (mm): 83

	YES	NO
➢ Present of a second, third,.., multifunction hand control		X

Control Labeling (Lc)

- Lc1 = Proportion of controls having an associated title e.g. a label (*above the controls*) or indication *(e.g. icon, symbol)*: *68/73*
  Labels: In case of labels, the height of numerals and letters must be at least 2.5 mm (0.1 in)
  Icons and Symbols: In case of icons and symbols, consideration of the standard icons and symbols will be used based on ANSI/ASAE S304.7
- Lc2 = Colour – coding: Number of colours that are used: *7*

Functional Reach (Fr)

- Proportion of controls present within a radius of 750 mm (29.5 in) covering a 180° envelope in front of the operator: *48/73*

Placement of Controls (Pc)

- Proportion of controls present on the right hand side of the operator: *63/73*

Suitability of Controls (Sc)

- Proportion of controls where mode of action is appropriate to function: *69/73*

Fendt 920 Vario

Total number of control types = 6

Steering Wheel	=	1
Buttons	=	52
Hand – Levers	=	4
Knobs	=	9
Rocker Switches	=	6
Multifunction Control	=	1

Total number of controls 73

- Controls with Red Colour: *Controls related to the functioning of the implement*
  e.g. Hydraulic, PTO, 3–Point hitch.
- Controls with Green Colour: *Controls related to the motion of the tractor*
  e.g. Gearshift, Hand brake, Throttle, Reverser.
- Controls with Amber Colour: *Controls related to the internal environment*
  e.g. Air conditioning, Cigarette lighter, Radio channel selector, Radio volume.
- Controls with Blue Colour: *Controls related to the external environment*
  e.g. Headlights, Turn signal, Windshield wipers, Horn.

Data Collection Sheet for
Caterpillar Challenger MT 665B

Control	Type	Length (mm)	Width (mm)	Height (mm)	Sep/on (mm)	Arm Length	Diameter (mm)	Activation Force (kg)	Dis/nt (mm)	L4 Factor H. Lever	Rim Th/ss	Sw3 Factor	Angle (degrees)
Steering Wheel	Steering Wheel	N/A	N/A	N/A	N/A	N/A	388	N/A	N/A	N/A	28	1/3	50°
PTO RPM 1	Button	N/A	N/A	N/A	23	N/A	15	N/A	N/A	N/A	N/A	N/A	N/A
PTO RPM 2	Button	N/A	N/A	N/A	23	N/A	15	N/A	N/A	N/A	N/A	N/A	N/A
PTO RPM 3	Button	N/A	N/A	N/A	23	N/A	15	N/A	N/A	N/A	N/A	N/A	N/A
3 – Point Hitch	Rocker Switch	26	23	N/A	12	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
PTO Engagement	Button	N/A	N/A	N/A	70	N/A	28	N/A	N/A	N/A	N/A	N/A	N/A
Throttle	Hand – Lever	N/A	N/A	N/A	15	N/A	N/A	0.3	51	4/7	N/A	N/A	N/A
Gearshift – Reverser	Hand – Lever	N/A	N/A	N/A	62	N/A	N/A	1.2	88	4/7	N/A	N/A	N/A
Differential Lock	Rocker Switch	25	22	N/A	3	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Air Conditioning	Knob	N/A	N/A	11	12	N/A	30	N/A	N/A	N/A	N/A	N/A	N/A
Steering Wheel Adjustment	Hand – Lever	N/A	N/A	N/A	130	N/A	N/A	0.9	42	4/7	N/A	N/A	N/A
Windshield Wipers–Washer–Turn Signal & Horn	Hand – Lever	N/A	N/A	N/A	88	N/A	N/A	0.6	90	4/7	N/A	N/A	N/A
Windshield Defroster	Button	N/A	N/A	N/A	3	N/A	20	N/A	N/A	N/A	N/A	N/A	N/A
Headlights	Rocker Switch	25	21	N/A	3	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Hazard Lights	Rocker Switch	25	21	N/A	3	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Hydraulic Control 1	Button	N/A	N/A	N/A	10	N/A	12	N/A	N/A	N/A	N/A	N/A	N/A
Hydraulic Control 2	Button	N/A	N/A	N/A	10	N/A	12	N/A	N/A	N/A	N/A	N/A	N/A
Hydraulic Control 3	Button	N/A	N/A	N/A	10	N/A	12	N/A	N/A	N/A	N/A	N/A	N/A
Hydraulic Control 4	Button	N/A	N/A	N/A	10	N/A	12	N/A	N/A	N/A	N/A	N/A	N/A
Hydraulic Control 5	Button	N/A	N/A	N/A	10	N/A	12	N/A	N/A	N/A	N/A	N/A	N/A
Hydraulic Control 6	Button	N/A	N/A	N/A	20	N/A	12	N/A	N/A	N/A	N/A	N/A	N/A
Hydraulic Control 7	Button	N/A	N/A	N/A	20	N/A	12	N/A	N/A	N/A	N/A	N/A	N/A
Hydraulic Control 8	Toggle Switch	N/A	N/A	N/A	10	25	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Hydraulic Control 9	Toggle Switch	N/A	N/A	N/A	10	25	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Hydraulic Control 10	Toggle Switch	N/A	N/A	N/A	10	25	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Hydraulic Control 11	Toggle Switch	N/A	N/A	N/A	10	25	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Hydraulic Control 12	Knob	N/A	N/A	18	37	N/A	30	N/A	N/A	N/A	N/A	N/A	N/A
Fan Speed	Knob	N/A	N/A	11	12	N/A	30	N/A	N/A	N/A	N/A	N/A	N/A
Injection Button	Button	N/A	N/A	N/A	70	N/A	12	N/A	N/A	N/A	N/A	N/A	N/A
Height Adjustment	Knob	N/A	N/A	15	75	N/A	52	N/A	N/A	N/A	N/A	N/A	N/A

Operation Button 1	Button	N/A	N/A	N/A	40	N/A	12	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 2	Button	N/A	N/A	N/A	7	N/A	17	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 3	Button	N/A	N/A	N/A	7	N/A	17	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 4	Button	N/A	N/A	N/A	7	N/A	17	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 5	Button	N/A	N/A	N/A	7	N/A	17	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 6	Button	N/A	N/A	N/A	7	N/A	17	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 7	Button	N/A	N/A	N/A	7	N/A	17	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 8	Button	N/A	N/A	N/A	7	N/A	17	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 9	Button	N/A	N/A	N/A	7	N/A	17	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 10	Button	N/A	N/A	N/A	7	N/A	17	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 11	Button	N/A	N/A	N/A	8	N/A	13	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 12	Button	N/A	N/A	N/A	8	N/A	13	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 13	Button	N/A	N/A	N/A	8	N/A	13	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 14	Button	N/A	N/A	N/A	8	N/A	13	N/A	N/A	N/A	N/A	N/A	N/A
Cab Light 1	Button	N/A	N/A	N/A	250	N/A	26	N/A	N/A	N/A	N/A	N/A	N/A
Cab Light 2	Button	N/A	N/A	N/A	250	N/A	26	N/A	N/A	N/A	N/A	N/A	N/A

Hydraulic Control 1	Knob	N/A	N/A	21	27	N/A	18	N/A	N/A	N/A	N/A	N/A	N/A
Hydraulic Control 2	Knob	N/A	N/A	21	27	N/A	18	N/A	N/A	N/A	N/A	N/A	N/A
Hydraulic Control 3	Knob	N/A	N/A	21	27	N/A	18	N/A	N/A	N/A	N/A	N/A	N/A
Hydraulic Control 4	Knob	N/A	N/A	21	27	N/A	18	N/A	N/A	N/A	N/A	N/A	N/A
Hydraulic Control 5	Knob	N/A	N/A	21	27	N/A	18	N/A	N/A	N/A	N/A	N/A	N/A
Hydraulic Control 6	Knob	N/A	N/A	21	27	N/A	18	N/A	N/A	N/A	N/A	N/A	N/A
Hydraulic Control 7	Hand – Lever	N/A	N/A	N/A	51	N/A	N/A	0.7	100	4/7	N/A	N/A	N/A
Hydraulic Control 8	Hand – Lever	N/A	N/A	N/A	51	N/A	N/A	0.7	100	4/7	N/A	N/A	N/A
Hydraulic Control 9	Hand – Lever	N/A	N/A	N/A	51	N/A	N/A	0.7	100	4/7	N/A	N/A	N/A
Hydraulic Control 10	Rocker Switch	25	22	N/A	3	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Hydraulic Control 11	Rocker Switch	25	22	N/A	3	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Hydraulic Control 12	Rocker Switch	25	22	N/A	3	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Hydraulic Control 13	Rocker Switch	25	22	N/A	3	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Hydraulic Control 14	Rocker Switch	25	22	N/A	3	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 1	Button	N/A	N/A	N/A	4	N/A	16	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 2	Button	N/A	N/A	N/A	4	N/A	16	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 3	Button	N/A	N/A	N/A	4	N/A	16	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 4	Button	N/A	N/A	N/A	4	N/A	16	N/A	N/A	N/A	N/A	N/A	N/A

Operation Button 5	Button	N/A	N/A	N/A	4	N/A	16	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 6	Button	N/A	N/A	N/A	4	N/A	16	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 7	Button	N/A	N/A	N/A	4	N/A	16	N/A	N/A	N/A	N/A	N/A	N/A
Seat Adjustment 1	Rocker Switch	12	15	N/A	130	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Seat Adjustment 2	Rocker Switch	12	15	N/A	130	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Cigarette Lighter	Button	N/A	N/A	N/A	350	N/A	28	N/A	N/A	N/A	N/A	N/A	N/A

Multifunction Hand Controls (Mc)

	YES	NO
➢ Located at the right hand side of the operator	N/A	N/A

- ➢ Activation Force (kg) N/A
- ➢ Displacement (mm) N/A

	YES	NO
➢ Present of a second, third,.., multifunction hand control		X

Control Labeling (Lc)

- ➢ Lc1 = Proportion of controls having an associated title e.g. a label (*above the controls*) or indication *(e.g. icon, symbol)*: *66/70*
  Labels: In case of labels, the height of numerals and letters must be at least 2.5 mm (0.1 in)
  Icons and Symbols: In case of icons and symbols, consideration of the standard icons and symbols will be used based on ANSI/ASAE S304.7
- ➢ Lc2 = Colour – coding: Number of colours that are used: *5*

Functional Reach (Fr)

- ➢ Proportion of controls present within a radius of 750 mm (29.5 in) covering a 180° envelope in front of the operator: *64/70*

Placement of Controls (Pc)

- ➢ Proportion of controls present on the right hand side of the operator: *63/70*

Suitability of Controls (Sc)

- ➢ Proportion of controls where mode of action is appropriate to function: *70/70*

Caterpillar Challenger MT 665B

Total number of control types = 6

Steering Wheel	= 1
Buttons	= 37
Toggle Switches	= 4
Hand – Levers	= 7
Knobs	= 10
Rocker Switches	= 11

Total number of controls 70

- Controls with Red Colour: *Controls related to the functioning of the implement*
  e.g. Hydraulic, PTO, 3–Point hitch.
- Controls with Green Colour: *Controls related to the motion of the tractor*
  e.g. Gearshift, Hand brake, Throttle, Reverser.
- Controls with Amber Colour: *Controls related to the internal environment*
  e.g. Air conditioning, Cigarette lighter, Radio channel selector, Radio volume.
- Controls with Blue Colour: *Controls related to the external environment*
  e.g. Headlights, Turn signal, Windshield wipers, Horn.

Data Collection Sheet for Fendt 275 S

Control	Type	Length (mm)	Width (mm)	Height (mm)	Sep/on (mm)	Arm Length	Diameter (mm)	Activation Force (kg)	Dis/nt (mm)	L4 Factor H. Lever	Rim Th/ss	Sw3 Factor	Angle (degrees)
Steering Wheel	Steering Wheel	N/A	N/A	N/A	N/A	N/A	528	N/A	N/A	N/A	34	0/2	50°
3 – Point Hitch	Hand – Lever	N/A	N/A	N/A	105	N/A	N/A	9	127	3/7	N/A	N/A	N/A
Gearshift	Hand – Lever	N/A	N/A	N/A	57	N/A	N/A	11	233	3/7	N/A	N/A	N/A
Headlights 1	Button	N/A	N/A	N/A	58	N/A	23	N/A	N/A	N/A	N/A	N/A	N/A
Turn Signal – Horn	Hand – Lever	N/A	N/A	N/A	78	N/A	N/A	0.6	89	3/7	N/A	N/A	N/A
Hazard Lights	Button	N/A	N/A	N/A	46	N/A	23	N/A	N/A	N/A	N/A	N/A	N/A
Hydraulic Control 1	Hand – Lever	N/A	N/A	N/A	88	N/A	N/A	0.5	78	3/7	N/A	N/A	N/A
Hydraulic Control 2	Hand – Lever	N/A	N/A	N/A	130	N/A	N/A	23	368	3/7	N/A	N/A	N/A
Hydraulic Control 3	Rocker Switch	23	4	N/A	15	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Hydraulic Control 4	Knob	N/A	N/A	32	46	N/A	9	N/A	N/A	N/A	N/A	N/A	N/A
Hydraulic Control 5	Knob	N/A	N/A	25	65	N/A	9	N/A	N/A	N/A	N/A	N/A	N/A
Hydraulic Control 6	Knob	N/A	N/A	14	70	N/A	22	N/A	N/A	N/A	N/A	N/A	N/A
Injection Button	Toggle Switch	N/A	N/A	N/A	32	8	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Hand Brake 1	Hand – Lever	N/A	N/A	N/A	67	N/A	N/A	8	321	3/7	N/A	N/A	N/A
Hand Brake 2	Hand – Lever	N/A	N/A	N/A	67	N/A	N/A	8	321	3/7	N/A	N/A	N/A
Headlights 2	Button	N/A	N/A	N/A	67	N/A	23	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 1	Button	N/A	N/A	N/A	54	N/A	10	N/A	N/A	N/A	N/A	N/A	N/A

Multifunction Hand Controls (Mc)

	YES	NO
➢ Located at the right hand side of the operator	N/A	N/A

- ➢ Activation Force (kg) N/A
- ➢ Displacement (mm) N/A

	YES	NO
➢ Present of a second, third,.., multifunction hand control		X

Control Labeling (Lc)

- ➢ Lc1 = Proportion of controls having an associated title e.g. a label (*above the controls*) or indication *(e.g. icon, symbol)*: *11/17*
  Labels: In case of labels, the height of numerals and letters must be at least 2.5 mm (0.1 in)
  Icons and Symbols: In case of icons and symbols, consideration of the standard icons and symbols will be used based on ANSI/ASAE S304.7
- ➢ Lc2 = Colour – coding: Number of colours that are used: *3*

Functional Reach (Fr)

- ➢ Proportion of controls present within a radius of 750 mm (29.5 in) covering a 180° envelope in front of the operator: *9/17*

Placement of Controls (Pc)

- ➢ Proportion of controls present on the right hand side of the operator: *9/17*

Suitability of Controls (Sc)

- ➢ Proportion of controls where mode of action is appropriate to function: *10/17*

Fendt 275 S

Total number of control types = 6

Steering Wheel	=	1
Buttons	=	4
Hand – Levers	=	7
Knobs	=	3
Rocker Switches	=	1
Toggle Switches	=	1

Total number of controls **17**

- Controls with Red Colour: *Controls related to the functioning of the implement*
  e.g. Hydraulic, PTO, 3–Point hitch.
- Controls with Green Colour: *Controls related to the motion of the tractor*
  e.g. Gearshift, Hand brake, Throttle, Reverser.
- Controls with Amber Colour: *Controls related to the internal environment*
  e.g. Air conditioning, Cigarette lighter, Radio channel selector, Radio volume.
- Controls with Blue Colour: *Controls related to the external environment*
  e.g. Headlights, Turn signal, Windshield wipers, Horn.

Data Collection Sheet for Hurlimann H-478

Control	Type	Length (mm)	Width (mm)	Height (mm)	Sep/on (mm)	Arm Length	Diameter (mm)	Activation Force (kg)	Dis/nt (mm)	L4 Factor H. Lever	Rim Th/ss	Sw3 Factor	Angle (degrees)
Steering Wheel	Steering Wheel	N/A	N/A	N/A	N/A	N/A	517	N/A	N/A	N/A	36	0/2	45°
3 – Point Hitch	Hand – Lever	N/A	N/A	N/A	102	N/A	N/A	5	435	6/11	N/A	N/A	N/A
Gearshift	Hand – Lever	N/A	N/A	N/A	79	N/A	N/A	17	391	6/11	N/A	N/A	N/A
Headlights 1	Hand – Lever	N/A	N/A	N/A	67	N/A	N/A	2	67	6/11	N/A	N/A	N/A
Turn Signal – Horn	Hand – Lever	N/A	N/A	N/A	74	N/A	N/A	0.5	79	6/11	N/A	N/A	N/A
Hazard Lights	Button	N/A	N/A	N/A	52	N/A	29	N/A	N/A	N/A	N/A	N/A	N/A
Hydraulic Control 1	Hand – Lever	N/A	N/A	N/A	89	N/A	N/A	12	467	6/11	N/A	N/A	N/A
Hydraulic Control 2	Hand – Lever	N/A	N/A	N/A	89	N/A	N/A	17	445	6/11	N/A	N/A	N/A
Hydraulic Control 3	Hand – Lever	N/A	N/A	N/A	89	N/A	N/A	18	393	6/11	N/A	N/A	N/A
Hydraulic Control 4	Hand – Lever	N/A	N/A	N/A	76	N/A	N/A	12	244	6/11	N/A	N/A	N/A
Hydraulic Control 5	Knob	N/A	N/A	10	16	N/A	26	N/A	N/A	N/A	N/A	N/A	N/A
Fan Speed	Knob	N/A	N/A	17	62	N/A	9	N/A	N/A	N/A	N/A	N/A	N/A
Injection Button	Toggle Switch	N/A	N/A	N/A	9	9	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Reverser	Hand – Lever	N/A	N/A	N/A	93	N/A	N/A	11	403	6/11	N/A	N/A	N/A
Headlights 2	Hand – Lever	N/A	N/A	N/A	105	N/A	N/A	2	67	6/11	N/A	N/A	N/A
Hand – Brake	Hand – Lever	N/A	N/A	N/A	93	N/A	N/A	20	445	6/11	N/A	N/A	N/A

Hydraulic Control 6	Rocker Switch	26	6	N/A	11	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Hydraulic Control 7	Rocker Switch	26	6	N/A	11	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Multifunction Hand Controls (Mc)

	YES	NO
➢ Located at the right hand side of the operator	N/A	N/A

- Activation Force (kg): N/A
- Displacement (mm): N/A

	YES	NO
➢ Present of a second, third,.., multifunction hand control		X

Control Labeling (Lc)

- Lc1 = Proportion of controls having an associated title e.g. a label (*above the controls*) or indication *(e.g. icon, symbol)*: *8/18*
  Labels: In case of labels, the height of numerals and letters must be at least 2.5 mm (0.1 in)
  Icons and Symbols: In case of icons and symbols, consideration of the standard icons and symbols will be used based on ANSI/ASAE S304.7
- Lc2 = Colour – coding: Number of colours that are used: *5*

Functional Reach (Fr)

- Proportion of controls present within a radius of 750 mm (29.5 in) covering a 180° envelope in front of the operator: *9/18*

Placement of Controls (Pc)

- Proportion of controls present on the right hand side of the operator: *8/18*

Suitability of Controls (Sc)

- Proportion of controls where mode of action is appropriate to function: *9/18*

Hurlimann H-478

Total number of control types = 6

Steering Wheel	= 1
Buttons	= 1
Hand – Levers	= 11
Knobs	= 2
Rocker Switches	= 2
Toggle Switches	= 1
Total number of controls	**18**

- Controls with Red Colour: *Controls related to the functioning of the implement e.g. Hydraulic, PTO, 3–Point hitch.*
- Controls with Green Colour: *Controls related to the motion of the tractor e.g. Gearshift, Hand brake, Throttle, Reverser.*
- Controls with Amber Colour: *Controls related to the internal environment e.g. Air conditioning, Cigarette lighter, Radio channel selector, Radio volume.*
- Controls with Blue Colour: *Controls related to the external environment e.g. Headlights, Turn signal, Windshield wipers, Horn.*

Data Collection Sheet for Agrifull – Fiatagri 65

Control	Type	Length (mm)	Width (mm)	Height (mm)	Sep/on (mm)	Arm Length	Diameter (mm)	Activation Force (kg)	Dis/nt (mm)	L4 Factor H. Lever	Rim Th/ss	Sw3 Factor	Angle (degrees)
Steering Wheel	Steering Wheel	N/A	N/A	N/A	N/A	N/A	531	N/A	N/A	N/A	34	0/1	75°
PTO RPM	Toggle Switch	N/A	N/A	N/A	40	9	N/A	N/A	N/A	N/A	N/A	N/A	N/A
3 – Point Hitch	Hand – Lever	N/A	N/A	N/A	56	N/A	N/A	19	221	3/7	N/A	N/A	N/A
Gearshift	Hand – Lever	N/A	N/A	N/A	56	N/A	N/A	11	367	3/7	N/A	N/A	N/A
Turn Signal – Horn	Hand – Lever	N/A	N/A	N/A	78	N/A	N/A	0.85	75	3/7	N/A	N/A	N/A
Hydraulic Control 1	Hand – Lever	N/A	N/A	N/A	87	N/A	N/A	21	380	3/7	N/A	N/A	N/A
Hydraulic Control 2	Hand – Lever	N/A	N/A	N/A	87	N/A	N/A	21	389	3/7	N/A	N/A	N/A
Hydraulic Control 3	Knob	N/A	N/A	28	36	N/A	10	N/A	N/A	N/A	N/A	N/A	N/A
Hydraulic Control 4	Knob	N/A	N/A	28	36	N/A	10	N/A	N/A	N/A	N/A	N/A	N/A
Hydraulic Control 5	Rotary Switch	14	25	14	34	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Reverser	Hand – Lever	N/A	N/A	N/A	56	N/A	N/A	22	403	3/7	N/A	N/A	N/A
Hand – Brake	Hand – Lever	N/A	N/A	N/A	68	N/A	N/A	9	423	3/7	N/A	N/A	N/A
Height Adjustment	Knob	N/A	N/A	10	110	N/A	10	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 1	Button	N/A	N/A	N/A	54	N/A	28	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 2	Button	N/A	N/A	N/A	35	N/A	33	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 3	Button	N/A	N/A	N/A	13	N/A	21	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 4	Button	N/A	N/A	N/A	43	N/A	10	N/A	N/A	N/A	N/A	N/A	N/A

Multifunction Hand Controls (Mc)

	YES	NO
➢ Located at the right hand side of the operator	N/A	N/A

➢ Activation Force (kg) N/A

➢ Displacement (mm) N/A

	YES	NO
➢ Present of a second, third,.., multifunction hand control		X

Control Labeling (Lc)

➢ Lc1 = Proportion of controls having an associated title e.g. a label (*above the controls*) or indication *(e.g. icon, symbol)*: *7/17*
Labels: In case of labels, the height of numerals and letters must be at least 2.5 mm (0.1 in)
Icons and Symbols: In case of icons and symbols, consideration of the standard icons and symbols will be used based on ANSI/ASAE S304.7

➢ Lc2 = Colour – coding: Number of colours that are used: *2*

Functional Reach (Fr)

➢ Proportion of controls present within a radius of 750 mm (29.5 in) covering a 180° envelope in front of the operator: *9/17*

Placement of Controls (Pc)

➢ Proportion of controls present on the right hand side of the operator: *5/17*

Suitability of Controls (Sc)

➢ Proportion of controls where mode of action is appropriate to function: *10/17*

Agrifull – Fiatagri 65

Total number of control types = 6

- Steering Wheel = 1
- Buttons = 4
- Hand – Levers = 7
- Knobs = 3
- Rotary Switches = 1
- Toggle Switches = 1

Total number of controls **17**

- Controls with Red Colour: *Controls related to the functioning of the implement e.g. Hydraulic, PTO, 3–Point hitch.*
- Controls with Green Colour: *Controls related to the motion of the tractor e.g. Gearshift, Hand brake, Throttle, Reverser.*
- Controls with Amber Colour: *Controls related to the internal environment e.g. Air conditioning, Cigarette lighter, Radio channel selector, Radio volume.*
- Controls with Blue Colour: *Controls related to the external environment e.g. Headlights, Turn signal, Windshield wipers, Horn.*

Data Collection Sheet for Fiat 640

Control	Type	Length (mm)	Width (mm)	Height (mm)	Sep/on (mm)	Arm Length	Diameter (mm)	Activation Force (kg)	Dis/nt (mm)	L4 Factor H. Lever	Rim Th/ss	Sw3 Factor	Angle (degrees)
Steering Wheel	Steering Wheel	N/A	N/A	N/A	N/A	N/A	526	N/A	N/A	N/A	15	0/1	80°
3 – Point Hitch	Hand – Lever	N/A	N/A	N/A	109	N/A	N/A	19	405	3/6	N/A	N/A	N/A
Gearshift	Hand – Lever	N/A	N/A	N/A	69	N/A	N/A	17	391	3/6	N/A	N/A	N/A
Turn Signal	Hand – Lever	N/A	N/A	N/A	73	N/A	N/A	0.9	71	3/6	N/A	N/A	N/A
Hydraulic Control 1	Hand – Lever	N/A	N/A	N/A	67	N/A	N/A	6	432	3/6	N/A	N/A	N/A
Hydraulic Control 2	Hand – Lever	N/A	N/A	N/A	67	N/A	N/A	6	443	3/6	N/A	N/A	N/A
Reverser	Hand – Lever	N/A	N/A	N/A	45	N/A	N/A	19	234	3/6	N/A	N/A	N/A
Horn	Button	N/A	N/A	N/A	21	N/A	10	N/A	N/A	N/A	N/A	N/A	N/A
Hydraulic Control 3	Rotary Switch	19	34	8	43	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Multifunction Hand Controls (Mc)

	YES	NO
➢ Located at the right hand side of the operator	N/A	N/A

- ➢ Activation Force (kg) N/A
- ➢ Displacement (mm) N/A

	YES	NO
➢ Present of a second, third,.., multifunction hand control		X

Control Labeling (Lc)

- ➢ Lc1 = Proportion of controls having an associated title e.g. a label (*above the controls*) or indication *(e.g. icon, symbol)*: *2/9*
  Labels: In case of labels, the height of numerals and letters must be at least 2.5 mm (0.1 in)
  Icons and Symbols: In case of icons and symbols, consideration of the standard icons and symbols will be used based on ANSI/ASAE S304.7
- ➢ Lc2 = Colour – coding: Number of colours that are used: *1*

Functional Reach (Fr)

- ➢ Proportion of controls present within a radius of 750 mm (29.5 in) covering a 180° envelope in front of the operator: *4/9*

Placement of Controls (Pc)

- ➢ Proportion of controls present on the right hand side of the operator: *2/9*

Suitability of Controls (Sc)

- ➢ Proportion of controls where mode of action is appropriate to function: *4/9*

Fiat 640

Total number of control types = 4

Steering Wheel	=	1
Buttons	=	1
Hand – Levers	=	6
Rotary Switches	=	1

Total number of controls **9**

- Controls with Red Colour: *Controls related to the functioning of the implement*
  e.g. Hydraulic, PTO, 3–Point hitch.
- Controls with Green Colour: *Controls related to the motion of the tractor*
  e.g. Gearshift, Hand brake, Throttle, Reverser.
- Controls with Amber Colour: *Controls related to the internal environment*
  e.g. Air conditioning, Cigarette lighter, Radio channel selector, Radio volume.
- Controls with Blue Colour: *Controls related to the external environment*
  e.g. Headlights, Turn signal, Windshield wipers, Horn.

Data Collection Sheet for Steyr 650

Control	Type	Length (mm)	Width (mm)	Height (mm)	Sep/on (mm)	Arm Length	Diameter (mm)	Activation Force (kg)	Dis/nt (mm)	L4 Factor H. Lever	Rim Th/ss	Sw3 Factor	Angle (degrees)
Steering Wheel	Steering Wheel	N/A	N/A	N/A	N/A	N/A	519	N/A	N/A	N/A	17	0/1	70°
Gearshift	Hand – Lever	N/A	N/A	N/A	69	N/A	N/A	4	432	3/6	N/A	N/A	N/A
Turn Signal – Horn	Hand – Lever	N/A	N/A	N/A	73	N/A	N/A	0.8	61	3/6	N/A	N/A	N/A
Hydraulic Control 1	Hand – Lever	N/A	N/A	N/A	88	N/A	N/A	21	397	3/6	N/A	N/A	N/A
Reverser	Hand – Lever	N/A	N/A	N/A	88	N/A	N/A	22	411	3/6	N/A	N/A	N/A
Hand Brake 1	Hand – Lever	N/A	N/A	N/A	77	N/A	N/A	23	387	3/6	N/A	N/A	N/A
Hand Brake 2	Hand – Lever	N/A	N/A	N/A	76	N/A	N/A	23	387	3/6	N/A	N/A	N/A
Operation Button 1	Button	N/A	N/A	N/A	54	N/A	29	N/A	N/A	N/A	N/A	N/A	N/A
Operation Button 2	Button	N/A	N/A	N/A	58	N/A	29	N/A	N/A	N/A	N/A	N/A	N/A

Multifunction Hand Controls (Mc)

	YES	NO
➢ Located at the right hand side of the operator	N/A	N/A

➢ Activation Force (kg) N/A

➢ Displacement (mm) N/A

	YES	NO
➢ Present of a second, third,.., multifunction hand control		X

Control Labeling (Lc)

➢ Lc1 = Proportion of controls having an associated title e.g. a label (*above the controls*) or indication *(e.g. icon, symbol)*: *2/9*
Labels: In case of labels, the height of numerals and letters must be at least 2.5 mm (0.1 in)
Icons and Symbols: In case of icons and symbols, consideration of the standard icons and symbols will be used based on ANSI/ASAE S304.7

➢ Lc2 = Colour – coding: Number of colours that are used: *2*

Functional Reach (Fr)

➢ Proportion of controls present within a radius of 750 mm (29.5 in) covering a 180° envelope in front of the operator: *4/9*

Placement of Controls (Pc)

➢ Proportion of controls present on the right hand side of the operator: *2/9*

Suitability of Controls (Sc)

➢ Proportion of controls where mode of action is appropriate to function: *3/9*

Steyr 650

Total number of control types =	3	
✦ Steering Wheel	= 1	
✦ Buttons	= 2	
✦ Hand – Levers	= 6	
Total number of controls	**9**	

- Controls with Red Colour: *Controls related to the functioning of the implement*
  e.g. Hydraulic, PTO, 3–Point hitch.
- Controls with Green Colour: *Controls related to the motion of the tractor*
  e.g. Gearshift, Hand brake, Throttle, Reverser.
- Controls with Amber Colour: *Controls related to the internal environment*
  e.g. Air conditioning, Cigarette lighter, Radio channel selector, Radio volume.
- Controls with Blue Colour: *Controls related to the external environment*
  e.g. Headlights, Turn signal, Windshield wipers, Horn.

Data Collection Sheet for New Holland S 230

Control	Type	Length (mm)	Width (mm)	Height (mm)	Sep/on (mm)	Arm Length	Diameter (mm)	Activation Force (kg)	Dis/nt (mm)	L4 Factor H. Lever	Rim Th/ss	Sw3 Factor	Angle (degrees)
Steering Wheel	Steering Wheel	N/A	N/A	N/A	N/A	N/A	519	N/A	N/A	N/A	35	0/1	65°
3 – Point Hitch	Hand – Lever	N/A	N/A	N/A	69	N/A	N/A	18	387	2/7	N/A	N/A	N/A
Gearshift	Hand – Lever	N/A	N/A	N/A	103	N/A	N/A	19	423	2/7	N/A	N/A	N/A
Turn Signal – Horn	Hand – Lever	N/A	N/A	N/A	81	N/A	N/A	0.5	87	2/7	N/A	N/A	N/A
Hydraulic Control 1	Hand – Lever	N/A	N/A	N/A	96	N/A	N/A	10	322	2/7	N/A	N/A	N/A
Hydraulic Control 2	Hand – Lever	N/A	N/A	N/A	96	N/A	N/A	18	380	2/7	N/A	N/A	N/A
Hydraulic Control 3	Knob	N/A	N/A	10	13	N/A	7	N/A	N/A	N/A	N/A	N/A	N/A
Hydraulic Control 4	Knob	N/A	N/A	27	58	N/A	7	N/A	N/A	N/A	N/A	N/A	N/A
Hydraulic Control 5	Knob	N/A	N/A	27	56	N/A	10	N/A	N/A	N/A	N/A	N/A	N/A
Reverser	Hand – Lever	N/A	N/A	N/A	74	N/A	N/A	21	398	2/7	N/A	N/A	N/A
Hand Brake	Hand – Lever	N/A	N/A	N/A	74	N/A	N/A	19	402	2/7	N/A	N/A	N/A
Operation Button 1	Button	N/A	N/A	N/A	33	N/A	29	N/A	N/A	N/A	N/A	N/A	N/A

Multifunction Hand Controls (Mc)

	YES	NO
➢ Located at the right hand side of the operator	N/A	N/A

- ➢ Activation Force (kg) N/A
- ➢ Displacement (mm) N/A

	YES	NO
➢ Present of a second, third,.., multifunction hand control		X

Control Labeling (Lc)

- ➢ Lc1 = Proportion of controls having an associated title e.g. a label (*above the controls*) or indication *(e.g. icon, symbol)*: *4/12*
  Labels: In case of labels, the height of numerals and letters must be at least 2.5 mm (0.1 in)
  Icons and Symbols: In case of icons and symbols, consideration of the standard icons and symbols will be used based on ANSI/ASAE S304.7
- ➢ Lc2 = Colour – coding: Number of colours that are used: *3*

Functional Reach (Fr)

- ➢ Proportion of controls present within a radius of 750 mm (29.5 in) covering a 180° envelope in front of the operator: *5/12*

Placement of Controls (Pc)

- ➢ Proportion of controls present on the right hand side of the operator: *2/12*

Suitability of Controls (Sc)

- ➢ Proportion of controls where mode of action is appropriate to function: *5/12*

New Holland S 230

Total number of control types = 4

- Steering Wheel = 1
- Buttons = 1
- Hand – Levers = 7
- Knobs = 3

Total number of controls **12**

- Controls with Red Colour: *Controls related to the functioning of the implement*
  e.g. Hydraulic, PTO, 3–Point hitch.
- Controls with Green Colour: *Controls related to the motion of the tractor*
  e.g. Gearshift, Hand brake, Throttle, Reverser.
- Controls with Amber Colour: *Controls related to the internal environment*
  e.g. Air conditioning, Cigarette lighter, Radio channel selector, Radio volume.
- Controls with Blue Colour: *Controls related to the external environment*
  e.g. Headlights, Turn signal, Windshield wipers, Horn.

Appendix C

Questionnaires and Responses

Questionnaire for Frequency of Tractor Controls Use

QUESTIONNAIRE FOR FREQUENCY OF TRACTOR CONTROLS USE

Guidelines:

Rank the following categories of controls (from 1 to 5 with 1 being the most frequently used control) according to their frequency of use during a typical day of operation.
Please assume a tillage operation.

☐ Steering Wheel

☐ Controls related to the functioning of the implement
e.g. Hydraulic, PTO, 3–Point hitch.

☐ Controls related to the motion of the tractor
e.g. Gearshift, Hand brake, Throttle, Reverser.

☐ Controls related to the internal environment
e.g. Air conditioning, Cigarette lighter, Radio channel selector, Radio volume.

☐ Controls related to the external environment
e.g. Headlights, Turn signal, Windshield wipers, Horn.

Responses from Agricultural Tractor Operators

Appendix B: **QUESTIONNAIRE FOR FREQUENCY OF TRACTOR CONTROLS USE**

Guidelines:

Rank the following categories of controls (from 1 to 5 with 1 being the most frequently used control) according to their frequency of use during a typical day of operation.
Please assume a tillage operation.

[1] Steering Wheel

[2] Controls related to the functioning of the implement
e.g. Hydraulic, PTO, 3–Point hitch.

[3] Controls related to the motion of the tractor
e.g. Gearshift, Hand brake, Throttle, Reverser.

[4] Controls related to the internal environment
e.g. Air conditioning, Cigarette lighter, Radio channel selector, Radio volume.

[5] Controls related to the external environment
e.g. Headlights, Turn signal, Windshield wipers, Horn.

Appendix B: <u>**QUESTIONNAIRE FOR FREQUENCY OF TRACTOR CONTROLS USE**</u>

Guidelines:

Rank the following categories of controls (from 1 to 5 with 1 being the most frequently used control) according to their frequency of use during a typical day of operation.
Please assume a tillage operation.

[1] Steering Wheel

[2] Controls related to the functioning of the implement
e.g. Hydraulic, PTO, 3–Point hitch.

[3] Controls related to the motion of the tractor
e.g. Gearshift, Hand brake, Throttle, Reverser.

[4] Controls related to the internal environment
e.g. Air conditioning, Cigarette lighter, Radio channel selector, Radio volume.

[5] Controls related to the external environment
e.g. Headlights, Turn signal, Windshield wipers, Horn.

Appendix B: QUESTIONNAIRE FOR FREQUENCY OF TRACTOR CONTROLS USE

Guidelines:

Rank the following categories of controls (from 1 to 5 with 1 being the most frequently used control) according to their frequency of use during a typical day of operation.
Please assume a tillage operation.

[1] Steering Wheel

[2] Controls related to the functioning of the implement
e.g. Hydraulic, PTO, 3–Point hitch.

[3] Controls related to the motion of the tractor
e.g. Gearshift, Hand brake, Throttle, Reverser.

[4] Controls related to the internal environment
e.g. Air conditioning, Cigarette lighter, Radio channel selector, Radio volume.

[5] Controls related to the external environment
e.g. Headlights, Turn signal, Windshield wipers, Horn.

Appendix B: **QUESTIONNAIRE FOR FREQUENCY OF TRACTOR CONTROLS USE**

Guidelines:

Rank the following categories of controls (from 1 to 5 with 1 being the most frequently used control) according to their frequency of use during a typical day of operation.
Please assume a tillage operation.

[1] Steering Wheel

[2] Controls related to the functioning of the implement
e.g. Hydraulic, PTO, 3–Point hitch.

[3] Controls related to the motion of the tractor
e.g. Gearshift, Hand brake, Throttle, Reverser.

[4] Controls related to the internal environment
e.g. Air conditioning, Cigarette lighter, Radio channel selector, Radio volume.

[5] Controls related to the external environment
e.g. Headlights, Turn signal, Windshield wipers, Horn.

Appendix B: **QUESTIONNAIRE FOR FREQUENCY OF TRACTOR CONTROLS USE**

Guidelines:

Rank the following categories of controls (from 1 to 5 with 1 being the most frequently used control) according to their frequency of use during a typical day of operation.

Please assume a tillage operation.

1	Steering Wheel
2	Controls related to the functioning of the implement *e.g. Hydraulic, PTO, 3–Point hitch.*
3	Controls related to the motion of the tractor *e.g. Gearshift, Hand brake, Throttle, Reverser.*
4	Controls related to the internal environment *e.g. Air conditioning, Cigarette lighter, Radio channel selector, Radio volume.*
5	Controls related to the external environment *e.g. Headlights, Turn signal, Windshield wipers, Horn.*

Appendix B: **QUESTIONNAIRE FOR FREQUENCY OF TRACTOR CONTROLS USE**

Guidelines:

Rank the following categories of controls (from 1 to 5 with 1 being the most frequently used control) according to their frequency of use during a typical day of operation.
Please assume a tillage operation.

1 Steering Wheel

2 Controls related to the functioning of the implement
e.g. Hydraulic, PTO, 3–Point hitch.

3 Controls related to the motion of the tractor
e.g. Gearshift, Hand brake, Throttle, Reverser.

4 Controls related to the internal environment
e.g. Air conditioning, Cigarette lighter, Radio channel selector, Radio volume.

5 Controls related to the external environment
e.g. Headlights, Turn signal, Windshield wipers, Horn.

Appendix B: **QUESTIONNAIRE FOR FREQUENCY OF TRACTOR CONTROLS USE**

Guidelines:

Rank the following categories of controls (from 1 to 5 with 1 being the most frequently used control) according to their frequency of use during a typical day of operation.

Please assume a tillage operation.

1	Steering Wheel
2	Controls related to the functioning of the implement *e.g. Hydraulic, PTO, 3–Point hitch.*
3	Controls related to the motion of the tractor *e.g. Gearshift, Hand brake, Throttle, Reverser.*
4	Controls related to the internal environment *e.g. Air conditioning, Cigarette lighter, Radio channel selector, Radio volume.*
5	Controls related to the external environment *e.g. Headlights, Turn signal, Windshield wipers, Horn.*

Appendix B: **QUESTIONNAIRE FOR FREQUENCY OF TRACTOR CONTROLS USE**

Guidelines:

Rank the following categories of controls (from 1 to 5 with 1 being the most frequently used control) according to their frequency of use during a typical day of operation.
Please assume a tillage operation.

1	Steering Wheel
2	Controls related to the functioning of the implement *e.g. Hydraulic, PTO, 3–Point hitch.*
3	Controls related to the motion of the tractor *e.g. Gearshift, Hand brake, Throttle, Reverser.*
4	Controls related to the internal environment *e.g. Air conditioning, Cigarette lighter, Radio channel selector, Radio volume.*
5	Controls related to the external environment *e.g. Headlights, Turn signal, Windshield wipers, Horn.*

Appendix B: **QUESTIONNAIRE FOR FREQUENCY OF TRACTOR CONTROLS USE**

Guidelines:

Rank the following categories of controls (from 1 to 5 with 1 being the most frequently used control) according to their frequency of use during a typical day of operation.
Please assume a tillage operation.

[1] Steering Wheel

[2] Controls related to the functioning of the implement
e.g. Hydraulic, PTO, 3–Point hitch.

[3] Controls related to the motion of the tractor
e.g. Gearshift, Hand brake, Throttle, Reverser.

[4] Controls related to the internal environment
e.g. Air conditioning, Cigarette lighter, Radio channel selector, Radio volume.

[5] Controls related to the external environment
e.g. Headlights, Turn signal, Windshield wipers, Horn.

Appendix B: **QUESTIONNAIRE FOR FREQUENCY OF TRACTOR CONTROLS USE**

Guidelines:

Rank the following categories of controls (from 1 to 5 with 1 being the most frequently used control) according to their frequency of use during a typical day of operation.

Please assume a tillage operation.

1	Steering Wheel
2	Controls related to the functioning of the implement *e.g. Hydraulic, PTO, 3–Point hitch.*
3	Controls related to the motion of the tractor *e.g. Gearshift, Hand brake, Throttle, Reverser.*
4	Controls related to the internal environment *e.g. Air conditioning, Cigarette lighter, Radio channel selector, Radio volume.*
5	Controls related to the external environment *e.g. Headlights, Turn signal, Windshield wipers, Horn.*

Questionnaire for Weighting Ergonomic Factors in a Tractor Cab

Appendix A: QUESTIONNAIRE FOR WEIGHTING ERGONOMIC FACTORS IN A TRACTOR CAB

Guidelines:

Please complete the provided spaces next to each ergonomic factor by distributing 100 points among them according to their relative importance.
Also, provide a brief explanation for this selection.
Please feel free to add other ergonomic factors that are important according to your opinion.
In this case, add first the new factor(s) and continue by distributing 100 points among them [new factor(s) must be included] according to their relative importance.
Note: This questionnaire was developed exclusively to weigh ergonomic factors *in a tractor cab* and to give an explanation for this selection.
Your answers are considered to be essential for the work carried on towards my thesis project.
The sum of the points among the ergonomic factors must be 100.

Student: *Drakopoulos Dimitrios*
Organization: *University of Manitoba,*
Winnipeg, Canada
Department of Biosystems Engineering.
Advisor: *Dr. Danny Mann.*

☐ **Placement of Controls**

☐ **Functional Reach Grip**

☐ **Suitability of Controls**

☐ **Labelling of Controls**

☐ **Other factor:** ....

☐ **Other factor:** ....

Total Points: **100**

Explanation of the Ergonomics Factors

1. Placement of Controls

'All the tractor controls require accurate manipulation, they should be grouped on the right hand side of the operator, leaving his left hand available for steering at all times' (Purcell 1980).

Please give a brief explanation for giving this weight:

2. Functional Reach Grip

Functional reach grip is defined as the horizontal distance from the operator's shoulder to the tip of the thumb, measured with the subject's shoulders against the seat, the arm extended forward and the index finger touching the tip of the thumb.

Please give a brief explanation for giving this weight:

3. Suitability of Controls

Total number of controls where mode of action is appropriate to function. The above factor evaluates the suitability of controls in relation to the type of task required to be done.

Please give a brief explanation for giving this weight:

4. Labelling of Controls

Number of controls having an associated title e.g. a label (*above the controls*) or indication *(e.g. icon, symbol)*.

Please give a brief explanation for giving this weight:

Other Factor: ....

Please give a brief explanation for giving this weight:

Other Factor: ....

Please give a brief explanation for giving this weight:

Responses from Professional Ergonomists

Appendix A: QUESTIONNAIRE FOR WEIGHTING ERGONOMIC FACTORS IN A TRACTOR CAB

Guidelines:

Please complete the provided spaces next to each ergonomic factor by distributing 100 points among them according to their relative importance.
Also, provide a brief explanation for this selection.
Please feel free to add other ergonomic factors that are important according to your opinion.
In this case, add first the new factor(s) and continue by distributing 100 points among them [new factor(s) must be included] according to their relative importance.
Note: This questionnaire was developed exclusively to weigh ergonomic factors *in a tractor cab* and to give an explanation for this selection.
Your answers are considered to be essential for the work carried on towards my thesis project.
The sum of the points among the ergonomic factors must be 100.

Student: *Drakopoulos Dimitrios*
Organization: *University of Manitoba,*
Winnipeg, Canada
Department of Biosystems Engineering.
Advisor: *Dr. Danny Mann.*

30	**Placement of Controls**
10	**Functional Reach**
20	**Suitability of Controls**
40	**Labelling of Controls**

Total Points: **100**

Explanation of the Ergonomics Factors

1. Placement of Controls

'All the tractor controls require accurate manipulation, they should be grouped on the right hand side of the operator, leaving his left hand available for steering at all times' (Purcell 1980).

Please give a brief explanation for giving this weight:

Location of controls is critical for a safe and cohesive driving environment. Principles such as functional grouping, frequency and importance of use, driver expectation must be considered. The statement by Purcell is not entirely correct. Some controls should be located to the left (e.g. exterior lights), so they can be manipulated by a driver who is momentarily out of the truck.

2. Functional Reach

Functional reach grip is defined as the horizontal distance from the operator's shoulder to the tip of the thumb, measured with the subject's shoulders against the seat, the arm extended forward and the index finger touching the tip of the thumb.

Please give a brief explanation for giving this weight:
Important but a slight reach to certain controls is not a terrible thing and is a trade-off for a roomy interior.

3. Suitability of Controls

Total number of controls where mode of action is appropriate to function. The above factor evaluates the suitability of controls in relation to the type of task required to be done.

Please give a brief explanation for giving this weight:

A basic requirement for the overall design of controls. Control-movement compatibility should definitely be met.

4. Labelling of Controls

Number of controls having an associated title e.g. a label (*above the controls*) or indication *(e.g. icon, symbol).*

Please give a brief explanation for giving this weight:

This is absolutely critical. With out effective labeling, a control will be very confusing to the driver and may result in improper use.

Appendix A: QUESTIONNAIRE FOR WEIGHTING ERGONOMIC FACTORS IN A TRACTOR CAB

Guidelines:

Please complete the provided spaces next to each ergonomic factor by distributing 100 points among them according to their relative importance.
Also, provide a brief explanation for this selection.
Please feel free to add other ergonomic factors that are important according to your opinion.
In this case, add first the new factor(s) and continue by distributing 100 points among them [new factor(s) must be included] according to their relative importance.
Note: This questionnaire was developed exclusively to weigh ergonomic factors *in a tractor cab* and to give an explanation for this selection.
Your answers are considered to be essential for the work carried on towards my thesis project.
The sum of the points among the ergonomic factors must be 100.

Student: *Drakopoulos Dimitrios*
Organization: *University of Manitoba,*
Winnipeg, Canada
Department of Biosystems Engineering.
Advisor: *Dr. Danny Mann.*

Points	Factor
20	**Placement of Controls**
40	**Functional Reach**
30	**Suitability of Controls**
10	**Labelling of Controls**

Total Points: **100**

Explanation of the Ergonomics Factors

1. Placement of Controls

'All the tractor controls require accurate manipulation, they should be grouped on the right hand side of the operator, leaving his left hand available for steering at all times' (Purcell 1980).

Weighted third in importance. Less than optimal placement of controls would be compensated by adaptability of human operator.

Frequently operated controls should be located in most convenient location. Less frequently operated controls and controls with catastrophic consequences if erroneously activated should be placed in less convenient locations, with increased separation from other controls.

2. Functional Reach

Functional reach grip is defined as the horizontal distance from the operator's shoulder to the tip of the thumb, measured with the subject's shoulders against the seat, the arm extended forward and the index finger touching the tip of the thumb.

Weighted most important, thinking that the functional reach grip is essential for the operator to maintain a comfortable seating position in the cab during long durations of operation. With a less than optimal functional reach grip, the operator would have to assume less comfortable positions which could lead to fatigue or negative physical symptoms.

3. Suitability of Controls

Total number of controls where mode of action is appropriate to function. The above factor evaluates the suitability of controls in relation to the type of task required to be done.

Weighted second in importance, because if the mode of action of controls is not appropriate for functions, operation will be prone to error. Also, inappropriate control actions can increase operator fatigue/physical problems.

4. Labelling of Controls

Number of controls having an associated title e.g. a label (*above the controls*) or indication *(e.g. icon, symbol).*

Weighted least important. Assuming tractor operators are very experienced and typically operate tractors over long durations, the labeling of controls has less impact on performance. It is likely that the operators will access individual controls by memory of their location and reach distance, rather than by labeling. Of course, some type of labeling/training manual is needed to initially familiarize operators new to the cab. But for normal operation, the labeling of controls can be viewed as less important.

Labeling for control that have critical consequences if erroneously activated is more important. However, ideally their safe operation is also addressed by control placement and functional reach grip.

Appendix A: QUESTIONNAIRE FOR WEIGHTING ERGONOMIC FACTORS IN A TRACTOR CAB

Guidelines:
Please complete the provided spaces next to each ergonomic factor by distributing 100 points among them according to their relative importance.
Also, provide a brief explanation for this selection.
Please feel free to add other ergonomic factors that are important according to your opinion.
In this case, add first the new factor(s) and continue by distributing 100 points among them [new factor(s) must be included] according to their relative importance.
Note: This questionnaire was developed exclusively to weigh ergonomic factors *in a tractor cab* and to give an explanation for this selection.
Your answers are considered to be essential for the work carried on towards my thesis project.
The sum of the points among the ergonomic factors must be 100.

Student: *Drakopoulos Dimitrios*
Organization: *University of Manitoba,*
Winnipeg, Canada
Department of Biosystems Engineering.
Advisor: *Dr. Danny Mann.*

Points	Factor
30	**Placement of Controls**
20	**Functional Reach**
40	**Suitability of Controls**
10	**Labelling of Controls**

Total Points: **100**

Explanation of the Ergonomics Factors

1. Placement of Controls

'All the tractor controls require accurate manipulation, they should be grouped on the right hand side of the operator, leaving his left hand available for steering at all times' (Purcell 1980).

Please give a brief explanation for giving this weight:
This definition is too rigid. Not all the controls need to be on the right hand side. Steering can be accomplished as long as both right and left hand are not required to activate controls AT THE SAME TIME. Some controls are simple ON-OFF functions which do not require "accurate manipulation" (if by ' accurate' Purcell meant 'precise').

2. Functional Reach

Functional reach grip is defined as the horizontal distance from the operator's shoulder to the tip of the thumb, measured with the subject's shoulders against the seat, the arm extended forward and the index finger touching the tip of the thumb.

Please give a brief explanation for giving this weight:

This factor can sometimes be violated.

3. Suitability of Controls

Total number of controls where mode of action is appropriate to function. The above factor evaluates the suitability of controls in relation to the type of task required to be done.

Please give a brief explanation for giving this weight:

I think this type of control/function compatibility is very important. Probable more important than factor 1 above.

4. Labelling of Controls

Number of controls having an associated title e.g. a label (*above the controls*) or indication *(e.g. icon, symbol).*

Please give a brief explanation for giving this weight:

It's always good to have redundant coding available.

Appendix A: QUESTIONNAIRE FOR WEIGHTING ERGONOMIC FACTORS IN A TRACTOR CAB

Guidelines:

Please complete the provided spaces next to each ergonomic factor by distributing 100 points among them according to their relative importance.
Also, provide a brief explanation for this selection.
Please feel free to add other ergonomic factors that are important according to your opinion.
In this case, add first the new factor(s) and continue by distributing 100 points among them [new factor(s) must be included] according to their relative importance.
Note: This questionnaire was developed exclusively to weigh ergonomic factors *in a tractor cab* and to give an explanation for this selection.
Your answers are considered to be essential for the work carried on towards my thesis project.
The sum of the points among the ergonomic factors must be 100.

Student: *Drakopoulos Dimitrios*
Organization: *University of Manitoba,*
Winnipeg, Canada
Department of Biosystems Engineering.
Advisor: *Dr. Danny Mann.*

30	**Placement of Controls**
15	**Functional Reach**
15	**Suitability of Controls**
40	**Labelling of Controls**

Total Points: **100**

Explanation of the Ergonomics Factors

1. Placement of Controls

'All the tractor controls require accurate manipulation, they should be grouped on the right hand side of the operator, leaving his left hand available for steering at all times' (Purcell 1980).

Please give a brief explanation for giving this weight:

Control Selection Factor - Until the fully electronic controls interface tractor cab appears - which may not be far away, the placement of tractor controls should conform to the ASAE published standards for control locations to simplify control learnability and minimize the need for control exploration prior to using the tractor for work by farm workers unfamiliar with a new tractor.

2. Functional Reach

Functional reach grip is defined as the horizontal distance from the operator's shoulder to the tip of the thumb, measured with the subject's shoulders against the seat, the arm extended forward and the index finger touching the tip of the thumb.

Please give a brief explanation for giving this weight:

Control Operation Factor - I feel this factor has importance from a usability perspective for three reasons:

First, farmers spend long hours in a seated position which can lead to fatigue.

Second, farmers have a high incidence of back or spinal conditions from injury or prolonged stress.

Third, some controls are often accessed when twisting backward, which limits forward or sideways reach.

Consequently, I would recommend that the initial horizontal reach to controls plus additive control motion should be a fraction of the horizontal reach limit for the 5^{th} percentile farmer.

3. Suitability of Controls

Total number of controls where mode of action is appropriate to function. The above factor evaluates the suitability of controls in relation to the type of task required to be done.

Please give a brief explanation for giving this weight:

Control Operation Factor - Error Minimization - I believe that this is an important factor - control motions to initiate an action should align with the motion of the function that the tractor is to take on. This is especially important for positioning and adjusting controls where the tractor equipment is being positioned in relation to nearby equipment and other workers. Where attention is focussed on the external environment, control motions that align with demanded external motions are likely to lead to less control errors.

4. Labelling of Controls

Number of controls having an associated title e.g. a label (*above the controls*) or indication *(e.g. icon, symbol).*

Please give a brief explanation for giving this weight:

Control Selection Factor - This factor is important for control recognition. Controls should follow the ASAE standards for colour assignment and should additionally employ differentiation of controls by size, shape or symbols to allow user selection and differentiation both visually or by feel.

Appendix A: QUESTIONNAIRE FOR WEIGHTING ERGONOMIC FACTORS IN A TRACTOR CAB

Guidelines:

Please complete the provided spaces next to each ergonomic factor by distributing 100 points among them according to their relative importance.
Also, provide a brief explanation for this selection.
Please feel free to add other ergonomic factors that are important according to your opinion.
In this case, add first the new factor(s) and continue by distributing 100 points among them [new factor(s) must be included] according to their relative importance.
Note: This questionnaire was developed exclusively to weigh ergonomic factors *in a tractor cab* and to give an explanation for this selection.
Your answers are considered to be essential for the work carried on towards my thesis project.
The sum of the points among the ergonomic factors must be 100.

Student: *Drakopoulos Dimitrios*
Organization: *University of Manitoba,*
Winnipeg, Canada
Department of Biosystems Engineering.
Advisor: *Dr. Danny Mann.*

40	**Placement of Controls**
40	**Functional Reach**
15	**Suitability of Controls**
5	**Labelling of Controls**

Total Points: **100**

Explanation of the Ergonomics Factors

1. Placement of Controls

'All the tractor controls require accurate manipulation, they should be grouped on the right hand side of the operator, leaving his left hand available for steering at all times' (Purcell 1980).

Please give a brief explanation for giving this weight:

2. Functional Reach

Functional reach grip is defined as the horizontal distance from the operator's shoulder to the tip of the thumb, measured with the subject's shoulders against the seat, the arm extended forward and the index finger touching the tip of the thumb.

Please give a brief explanation for giving this weight:

3. Suitability of Controls

Total number of controls where mode of action is appropriate to function. The above factor evaluates the suitability of controls in relation to the type of task required to be done.

Please give a brief explanation for giving this weight:

4. Labelling of Controls

Number of controls having an associated title e.g. a label (*above the controls*) or indication *(e.g. icon, symbol).*

Please give a brief explanation for giving this weight:

Appendix D

Consent Forms

Consent Form – Part A

Research Project Title:
A Mathematical Equation for Quantifying Control Functionality in Agricultural Tractors

Researchers:
Mr. Dimitrios Drakopoulos and Dr. Danny Mann

Organization:
University of Manitoba
Winnipeg, MB R3T 2N2
Canada

This consent form, a copy of which will be left with you for your records and reference, is only part of the process of informed consent. It should give you the basic idea of what the research is about and what your participation will involve. If you would like more detail about something mentioned here, or information not included here, you should feel free to ask. Please take the time to read this carefully and to understand any accompanying information.

I. Purpose of the Research

The purpose of this research, which is conducted for a Masters thesis is to develop a numerical index to assess the degree to which the tractor controls meets the requirements of the operators from the standpoint of accessibility. This index will be applied to compare the control accessibility between an old versus a modern tractor in order to determine the progress in ergonomic matters that has been undertaken during the last years. The numerical index to be developed will take into account different control design standards and some ergonomic factors that are considered important in describing the accessibility of tractor controls.

II. Research Procedure

Initially, a numerical index will be developed. Later, the final draft of the index will be applied to twelve different tractor cabs. The numerical index developed so far includes eight different categories of controls that are considered to be important for the tractor operation. These categories must be classified in terms of frequency of use. In order to determine their frequency of use, you will be asked to complete a questionnaire during a 15–minute interview. Later an evaluation of your answers will be conducted and the final classification will be determined.

III. Risk and Benefits

There are no risks or benefits associated with the subjects or any third parties. Benefits resulted from this study include the fact that at the end of this survey we will be able to rank the five different categories of controls that are considered to be important for the tractor operation in terms of their relative frequency of use. As a result, the final draft of the numerical index will be determined properly.

IV. Anonymity and Confidentiality

In order to obtain anonymity no name records will be preserved during the e–mail and interview process. No confidential records will be consulted during the study since no such records will exist. Your answers will be accessed only from the principal researcher Mr. Dimitrios Drakopoulos and his supervisor Dr. Danny Mann. In no case other person will be allowed to access your answers. After the study of the results will be completed, all the data will be destroyed. This procedure will take place at the end of September 2005. Until this time the data will be kept in Dr. Mann's office.

The data that will be collected from this survey will not be presented anywhere else (e.g. conferences, journals).

V. Feedback

A letter of appreciation by the principle researcher will be sent back to each participant including a summary of the results.

VI. Remuneration

No remuneration will be provided for participating in this study.

Your signature on this form indicates that you have understood to your satisfaction the information regarding participation in the research project and agree to participate as a subject. In no way does this waive your legal rights nor release the researchers, sponsors, or involved institutions from their legal and professional responsibilities. You are free to withdraw from the study at any time, and /or refrain from answering any questions you prefer to omit, without prejudice or consequence. Your continued participation should be as informed as your initial consent, so you should feel free to ask for clarification or new information throughout your participation.

Mr. Dimitrios Drakopoulos
Department of Biosystems Engineering
University of Manitoba
Winnipeg, MB R3T 5V6
Phone:
E–mail:

Dr. Danny Mann
Department of Biosystems Engineering
University of Manitoba
Winnipeg, MB R3T 5V6
Phone:
Fax:
E–mail:

This research has been approved by the Education/Nursing Research Ethics Board. If you have any concerns or complaints about this project you may contact any of the above-named persons or the Human Ethics Secretariat at 474-7122, or e-mail margaret_bowman@umanitoba.ca. A copy of this consent form has been given to you to keep for your records and reference.

Participant's Signature Date

Researcher and/or Delegate's Signature Date

Consent Form – Part B

Research Project Title:
A Mathematical Equation for Quantifying Control Functionality in Agricultural Tractors

Researchers:
Mr. Dimitrios Drakopoulos and Dr. Danny Mann

Organization:
University of Manitoba
Winnipeg, MB R3T 2N2
Canada

This consent form, a copy of which will be left with you for your records and reference, is only part of the process of informed consent. It should give you the basic idea of what the research is about and what your participation will involve. If you would like more detail about something mentioned here, or information not included here, you should feel free to ask. Please take the time to read this carefully and to understand any accompanying information.

VI. Purpose of the Research

The purpose of this research, which is conducted for a Masters thesis is to develop a numerical index to assess the degree to which the tractor controls meets the requirements of the operators from the standpoint of accessibility. This index will be applied to compare the control accessibility between an old versus a modern tractor in order to determine the progress in ergonomic issues that has been undertaken during the last years. The numerical index to be developed will take into account different control design standards and some ergonomic factors that are considered important in describing the accessibility of tractor controls.

VII. Research Procedure

Initially, a numerical index will be developed. The numerical index developed so far includes a total number of four ergonomic factors that are considered to be important in showing the easiness in which the operator can access the tractor controls. These factors must be categorized in terms of giving them the appropriate weight according to their importance. In order to determine their importance, you will be asked to complete a questionnaire which will be sent to you through e–mail requiring the proper weight in each factor and justification in your decision. The expected time to complete the questionnaire will be approximately 15 minutes. Later an evaluation of your answers will be conducted and the final weight will be given to each factor. Finally, the final draft of the numerical index will be applied to twelve different tractor cabs and an assessment of control's accessibility will be conducted.

VIII. Risk and Benefits

There are no risks or benefits associated with the subjects or any third parties. Benefits resulted from this study include the fact that at the end of this survey it will be able to rank the four mentioned ergonomic factors in terms of giving them the appropriate weight according to their importance. As a result, the final draft of the numerical index will be determined properly.

IX. Anonymity and Confidentiality

In order to obtain anonymity no name records will be preserved during the e–mail and interview process. No confidential records will be consulted during the study since no such records will exist. Your answers will be accessed only from the principal researcher Mr. Dimitrios Drakopoulos and his supervisor Dr. Danny Mann. In no case will another person be allowed to access your answers. After the study, the results will be completed and all the data will be destroyed. This procedure will take place at the end of September 2005. Until this time the data will be kept in Dr. Mann's office.

The data that will be collected from this survey will not be presented anywhere else (e.g. conferences, journals).

X. Feedback

A letter of appreciation by the principle researcher will be sent back to each participant explaining how their input may help in understanding the importance of the ergonomic factors mentioned in the questionnaire that they completed. In addition, the principal researcher is willing to provide, for each participant, a copy of the final results of the study by completing the proper box:

a. Yes, I would like to provide me a copy of the final results of the study: ☐

b. No, I would not like to provide me a copy of the final results of the study: ☐

VI. Remuneration

No remuneration will be provided for participating in this study.

Your signature on this form indicates that you have understood to your satisfaction the information regarding participation in the research project and agree to participate as a subject. In no way does this waive your legal rights nor release the researchers, sponsors, or involved institutions from their legal and professional responsibilities. You are free to withdraw from the study at any time, and /or refrain from answering any questions you prefer to omit, without prejudice or consequence. Your continued participation should be as informed as your initial consent, so you should feel free to ask for clarification or new information throughout your participation.

Mr. Dimitrios Drakopoulos
Department of Biosystems Engineering
University of Manitoba
Winnipeg, MB R3T 5V6
Phone:
E–mail:

Dr. Danny Mann
Department of Biosystems Engineering
University of Manitoba
Winnipeg, MB R3T 5V6
Phone:
Fax:
E–mail:

This research has been approved by the Education/Nursing Research Ethics Board. If you have any concerns or complaints about this project you may contact any of the above-named persons or the Human Ethics Secretariat at 474-7122, or e-mail margaret_bowman@umanitoba.ca. A copy of this consent form has been given to you to keep for your records and reference.

____

Participant's Signature Date

____

Researcher and/or Delegate's Signature Date

UNIVERSITY OF MANITOBA

OFFICE OF RESEARCH SERVICES
Office of the Vice-President (Research)

244 Engineering Bldg.
Winnipeg, MB R3T 5V6
Telephone: (204) 474-8418
Fax: (204) 261-0325
www.umanitoba.ca/research

APPROVAL CERTIFICATE

07 June 2005

TO: **Dimitrios Drakopoulos** (Advisor D. Mann)
Principal Investigator

FROM: **Stan Straw, Chair**
Education/Nursing Research Ethics Board (ENREB)

Re: **Protocol #E2005:057**
"A Mathematical Equation for Quantifying Control Functionality in Agricultural Tractors"

Please be advised that your above-referenced protocol has received human ethics approval by the **Education/Nursing Research Ethics Board**, which is organized and operates according to the Tri-Council Policy Statement. This approval is valid for one year only.

Any significant changes of the protocol and/or informed consent form should be reported to the Human Ethics Secretariat in advance of implementation of such changes.

Please note:

- **if you have funds pending human ethics approval, the auditor requires that you submit a copy of this Approval Certificate to Kathryn Bartmanovich, Research Grants & Contract Services (fax 261-0325), including the Sponsor name, before your account can be opened.**

- **if you have received multi-year funding for this research, responsibility lies with you to apply for and obtain Renewal Approval at the expiry of the initial one-year approval; otherwise the account will be locked.**