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Operator’s focusing scheme inside off-road vehicles

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NOMENCLATURE AND ABBREVIATIONS

FRMS	Fatigue risk management system
HSI	Human-system-interface
HCD	Human Centered Design
ROPS	Roll-over protective structures
GPS	Global Positioning System
OBD	On-Board Diagnostics
IVIS	In-vehicle information system
HAD	Highly automated driving
DSMS	Driver state monitoring systems
HFAuto	Human Factors in Automated driving
DSMS	Driver state monitoring systems
DIM	Driver impairment monitor
DIMS	Driver inattention monitor systems
DVM	Driver vigilance monitoring
HMI	Human machine interface
EOF	Eyes-Off-Road
AOI	Areas of interest
TOI	Time of interest
EYEMEAS	Mean Square Eye Closure
RMSE	Root Mean Square Error
MEANCLOS	Mean Eye Closure
AECS	Average Eye Closure Speed
PERCLOS	Percentage Eye Closure
TOR	Take over request
HD	High definition
OFS	Operator’s focusing scheme

1. INTRODUCTION, OBJECTIVES

In this chapter, the importance of the research topic is presented along with the objectives of this research.

1.1. Introduction

Increasing the productivity and ensuring the safety of an operation via reducing the human error is considered an area of interest for research activities in different industrial fields, especially the fields in which human error may lead to catastrophic consequences with severe accidents such as Nuclear, Aviation and Oil & Gas, Automobile and Transportation industrial fields. Safety oriented researches take a priority over the productivity-oriented researches, however; it is always being under researchers' scope to figure out operator's fatigue, workplace comfort, operator's response time to notifications and any other operator's behaviors which are valuable indicators in developing design bases and designing operational procedures.

Human behavior inside workplace is considered an important factor for the productivity, safety and security aspects, the human factor issue is always considered as main contributing factor to be studied and analyzed. The resulted data from such research activities are normally translated into working models to be followed or implemented directly in the related field.

Based on the criticality of human contribution for the studied field and the availability of research technology, the source data is extracted on probabilistic or deterministic basis. However; utilizing the right data will be reflected in the effectiveness of resulted model to correlate a specific human behavior or more to a unique result which will be transformed into decision or a contributing factor for decision making.

(Yazdi and Sadeghniiat-Haghighi, 2015) considered the workers' fatigue as a significant problem in modern industry, referring that to high demand jobs, long duty periods, disruption of circadian rhythms, and accumulative sleep debt that are common in many industries. They defined the fatigue as the result of integration of multiple factors such as time awake, time of day, and workload. The research conducted by two scientists investigated in a new field of sleep medicine called occupational sleep medicine to the purpose of maintaining best productivity and safety in the industrial settings.

The conducted research proposed enhancing the fatigue risk management system (FRMS) as a comprehensive approach that is based on applying scientific evidence of sleep knowledge to manage workers fatigue. It is developing rapidly in the highly safety demand jobs; especially truck drivers, pilots, and power plant workers. The objective of (Yazdi and Sadeghniiat-Haghighi, 2015) research was to explain about fatigue in the workplace with emphasis on its association work performance and errors/accidents. In addition to discussion regarding different methods of fatigue measurement and management.

(Hugo and Gertman, 2016) described how new design concepts in the nuclear industry can be analyzed and how Human-system-interface (HSI) technologies associated with new industrial processes might be considered. The research also described basis for an understanding of human as well as technology characteristics that could be incorporated into a prioritization scheme for technology selection and deployment plans.

It is found in many literature i.e. (Pravin et al., 2013) that; human error has been documented as a primary contributor to more than 70 percent of commercial airplane hull-loss accidents. While typically associated with flight operations, human error has also recently become a major concern in maintenance practices and air traffic management. Research and development centres in the leading manufacturers made the human factor as a priority, developing the models representing the change on operator's behaviour inside workplaces, such as Boeing human factors professionals work with engineers, pilots, and mechanics to apply the latest knowledge about the interface between human performance and commercial airplanes to help operators improve safety and efficiency in their daily operations.

A notable momentum of research activities has been already taken place in the in-road vehicle field during the recent few years. Starting by simulators development for safety related research activities until developing the state-of-the-art technologies to support the in-road real-time researches. In the literature review chapter, some of the experiments will be illustrated in terms of results, usability and methods. In order to take the advantage of the available literature developing the method of this research, the real-time eye glance behavior measuring techniques are utilized.

(Herdovics, 2013) mentioned a very important role of the academic sector improving the development of agricultural operations by problem resolving and developing the recommendations based on the advanced analysis of data to be used in advanced farming processes easily. Therefore; the availability of such models provides decision makers with a factual based method coming from deterministic data analysis.

Precision agriculture has arrived. Driven by advances in Big Data, precision agriculture will have a marked impact on traditional approaches to farming land. Applying technological advances in data collection and geo-location, precision agriculture uses technology to optimize yield and detect operating efficiencies: this is technology that will tell farmers when the best time is to plant and when is the right time to start harvesting; that will take input costs down, negate environmental impact, reduce fuel and cut down on fatigue.

Robert (2004) and Xuan (2007) showed that it is essential for the research activities to concentrate on making the necessary studies on the resources management to reach the precision farming concept. In this research, one of the targets is to develop dedicated models to different agricultural operations showing the impact of working hours on the accumulated mental and passive physical load. Which might be used directly by rural farming organization as an indicator of the required effort difference between different agricultural operations.

1.2. Objectives

For this research, accumulated knowledge from earlier researches will be used to develop the methodology of measuring the selected behavior and will be contributing to the design processes in the precision farming i.e. human resources, selection of the vehicle and time estimation of the production operation. According to the previous reviewed research, it has demonstrated that the research area of human behavior in the multitasking vehicles are not enough, comparing with the research activities in the other fields, despite of the importance of human factor contribution to ensure the productivity and safety of the executing of operations.

Using the modern eye-tracking systems technology with a powerful analyzer software will be used in tractor cabin after designing of experiment procedure and documentation to:

1- Validating a method for measuring the operator’s focusing scheme.

2- Modeling the change on focusing scheme of the operator along working hours for a certain AOI (the attached tool) in the windrowing agricultural operation.

3- Modeling the change on focusing scheme of the operator along working hours for a certain AOI (the attached tool) in the cultivating agricultural operation.

4- Modeling the change on focusing scheme of the operator along working hours for a certain AOI (the front mounted tool) in the harvesting agricultural operation.

5- Comparing and analyzing the resulted models.

6- Specifying the least AOIs inside tractor cabins in the baling agricultural operation based on deterministic data.

2. LITERATURE REVIEW

In this chapter, scientific entrance and the critical literature related to the research topic is presented, in addition to showing the gap in the literature.

2.1. Introduction

Operator's workplace design takes a priority to be developed to reach the highest level of Quality, safety, and productivity. Continual improvement of the workplace is yield from studies carried out on different approaches, each approach shall take into consideration many aspects, in this research; the results will be used for feeding the productivity and safety aspects with simple engineering solutions.

Operating an off-road vehicle is a complex task, needing a concurrent execution of various cognitive, physical, sensory, and psychomotor skills (Young and Regan, 2007), additionally to control attached tools to perform in-field productive tasks such as agricultural and industrial operations. Ensuring the comfortable ride is considered essential for any vehicle, as well as executing happily and safely requested operational tasks, to that end; the driver ergonomics comes to play as considered as an important parameter that cannot be neglected in the design phase of the vehicle (Hsiao et al., 2005).

When it comes to off-road vehicles, considering operator's ergonomics become much more important at the design stages, thus because of the expected sustainability of the vehicle in rough operating conditions. Which shall be based on reliable measures to support the decision-making process.

This research is made based on literature of the accumulated knowledge from diverse fields in which different studies and analysis are made to give the necessary input for Human Centered Design (HCD) process, adopting the state-of-the-art technologies and methodologies used for data collection and analysis for Human behavior inside the dedicated workplace. Better understanding of the operator's behaviors and its change according to the mental and physical workloads inside the workplace will lead to the optimal designs for higher productivity and safer operation.

Continual improvement is a key factor for successful of Automation business, especially when it comes to productive operations. Enhancement opportunities are continually proposed, optimized, and implemented to increase productivity throughout increasing the efficiency of the performance and decreasing the costs came from consequences of operators' errors.

Parallel to technological improvements and automation enhancements growth in agricultural vehicles, the operator actions and response are considered important values in the productivity formula. Therefore, decreasing Human Error with designing proper operational environment is considered valuable area of continual improvement. Human factors and ergonomics are concerned with the "fit" between the user, equipment, and their environments. It takes account of the user's capabilities and limitations in looking to ensure that tasks, functions, information, and the environment suit each user.

2.2. Agricultural vehicles background

Tractors are companions for many agriculture workers. Well-designed human – tractor interfaces, such as well-accommodated tractor operator enclosures can enhance operations productivity, comfort, and safety (Matthews, 1977), (Kaminaka, 1985), (Liljedahl et al., 1989) and (Hsiao et al., 2005).

Back to 1950s in Sweden, several fatal incidents involving tractor overturns caused strong public reaction and special concerns among the Swedish trade organizations. Many researches started to deal with human-tractor interface with main aims of simplifying the mechanical test work and minimizing variations in mechanical test results (Moberg, 1973).

At that time, researches did not examine, specifically, many design parameters such as obstacle of steering wheel, hand controls and protection frames. Thereafter; designing the operator space envelopes and tractor control locations to fit with operator's body size has been considered as important design elements (Adams et al., 1975, Purcell, 1980, Bottoms, 1983, SAE International, 1989, 1992, 1994 and Yadav and Tewari, 1998).

Currently; the applicable standards are setting design parameters including Adjustable seats, steering wheels and other controls have become the norm and new heavy tractors are universally equipped with rollover protective structures (ROPS), which include a seatbelt that keeps the operator within the bounds of the ROPS 'safety zone' (ASAE, 2000 a, b).

Many previous researches are conducted to enhance the operator comfort accommodation and safety. Designs ensure that a tractor cab and ROPS will accommodate the body size of agricultural workers are considered as good Human-Tractor interface designs (Hansson et al., 1970).

The cabin design in tractor vehicle has been taken into consideration from the productivity assurance prospective, adjustments for brake reach and linkages, seat position and seat height must be designed to position all potential operators so that they can; adequately; reach the brake controls and see over the tractor and beyond the protection frames. In addition, the cab space must be arranged in such a way that the steering wheel, hand controls and seat do not hinder the driver's operation.

The safety assurance prospective is considered as well at the design stage by standardizing the Rollover Protection Structures (ROPS), therefore; dimensions of ROPS should; adequately; accommodate tractor drivers during normal operation and protect them from injury during a rollover.

2.3. Human – machine interface in agricultural vehicles

Communication channels between operator and workplace is defined as control, in tractors; all devices added to allow the operator to "communicate" with the tractor in addition to its attached interfaces work on transmitting information are defined as controls (Purcell, 1980). Operator's ability to interact with individual controls compromising the control panel is representing a key factor in term of the functionality of the tractor system, as the control panel is an important part of the full system of the tractor (Langle et al., 1997).

Many studies have been carried out to find preferred locations of in certain types of tractor controls (Casey and Kiso, 1990), moreover; emphasizing how critical is the placement of controls in some tractors; stating that; it; actually; creates an obstacle to body movement (Hsiao et al., 2005).

However, the recent models of tractor cabins designs included more advanced interactive multimedia devices and control instruments (Fig. 2.1), which makes it necessary to reinvestigate the productivity of inducing such systems and how the focusing function of the operator will be changed along working hours.

Fig. 2.1. John Deere 6th series tractor interiors

2.4. Driver's attention literature for in-road vehicles

In-vehicle systems research is becoming a significant field as the market for in-vehicle systems continue to grow. As a consequence, researchers are increasingly concerned with opportunities and limitations of Human-machine-interface in moving vehicle. Especially aspects of attention constitute a challenge for in-vehicle systems development.

Bach et al., (2009) summarized the research activities related to the studies which were conducted in driving simulators (Fig.2.2) and real traffic driving, while lateral and longitudinal control and eye behavior were the most used measures. Results are demonstrated in (Tab. 2.1) in which a sample of researches conducted focusing on primary and secondary tasks in addition to researches focused on the eye glance behavior.

Fig. 2.2. Advanced car simulator for safety research and development

Table. 2.1. Classification of attention measures distributed over driving settings

(N) indicates the number of unique papers in the respective categories.

		No Driving (N=16)	Simulated Driving (N=52)	Controlled Driving (N=7)	Real Traffic Driving (N=30)
Primary task	Lateral Control (N=41)	(Salvucci et al., 2005)	(Alpern and Minardo, 2003) (Cnossen et al. 2004)	(Aguiló and Fumero, 2004) (Tijerina et al., 2000)	(Blanco, 1999) (Brown et al., 1969)
	Longitudinal Control (N=35)	(Salvucci et al., 2005)	(Alpern and Minardo, 2003) (Cnossen et al. 2004)	(Aguiló and Fumero, 2004) (Tijerina et al., 2000)	(Blanco, 1999) (Brown et al., 1969)
	Car Following Performance (N=16)		(Cnossen et al., 2000)	(Lee et al., 2001)	(Lamble et al., 1999)
	Driver Reaction (N=30)	(Bellotti et al., 2005)	(Bellotti et al., 2005)	(Aguiló and Fumero, 2004) (Lee et al., 2001)	(Bellotti et al., 2005)
Secondary task	Task Effectiveness (N=44)	(Cavedon et al., 2005)	(Alm and Nilsson, 1995)	(Lee et al., 2001)	(Blanco, 1999)
	Task Efficiency (N=21)	(Salvucci et al., 2005) (Bellotti et al., 2005)	(Bellotti et al., 2005)	(Tijerina et al., 2000)	(Bellotti et al., 2005)
Eye glance behavior	Eye Glance Frequency (N=28)	(Klauer et al., 2006) (McCarley et al., 2004)	(De waard et al., 1999) (Broy et al., 2006) (Lansdown, 2002) (Lee et al., 2005) (Mayer et al., 2002) (Salvucci et al., 2001) (Strayer and	(Aguiló and Fumero, 2004) (Tijerina et al., 2000)	(Blanco, 1999) (Chiang et al., 2004) (Gellatly, 1997) (Piechulla et al., 2003) (Strayer and Johnston, 2001) (Lai et al., 2001)

			Johnston, 2001) (Strayer et al., 2004)		
	Eye Glance Duration (N=27)	(Klauer et al., 2006) (McCarley et al., 2004) (Rockwell, 1988) (Wierville, 1993) (Zwahlen et al., 1988)	(De waard et al., 1999) (Broy et al., 2006) (Lansdown, 2002) (Lee et al., 2005) (Mayer et al., 2002) (Salvucci et al., 2001) (Strayer and Johnston, 2001) (Strayer et al., 2004) (Strayer et al., 2003) (Verwey and Zaidel, 2000)	(Aguiló and Fumero, 2004) (Tijerina et al., 2000)	(Chiang et al., 2004) (Gellatly, 1997) (Strayer and Johnston, 2001) (Lai et al., 2001)
	Eye Scanning Patterns (N=16)	(Klauer et al., 2006) (McCarley et al., 2004)	(Green, 2001) (Salvucci et al., 2001) (Strayer et al., 2003) (Wittmanna et al., 2005)	(Tijerina et al., 2000)	(Chiang et al., 2004) (Chiang et al., 2004) (Harbluk and Noy, 2002) (Strayer and Johnston, 2001) (Trbovich and Harbluk, 2003)

As resulted from Green, (1996) research, it is necessary to concentrate the research activities on the impact of in-vehicle system usage while driving. Which came in line with many researches aimed to understand the field of in-vehicle systems to be used in developing of standards, guidelines, rules, and methods which are used in the engineering design phase.

Studying the impact of such systems while driving was the subject of many researches were conducted on the distraction resulted from using the cell phones and its impact on the driving performance. As a result of many studies (Alm and Nilsson, 1995), (Hancock et al., 1999), (Harbluk and Noy., 2002), (McKnight et al., 1993), (Redelmeier and Tibshirani, 1997), (Schneider and Kiesler, 2005), (Strayer and Johnston, 2001) and (Trbovich and Harbluk, 2003), the cell phone usage, generally, will affect the driving performance. Even by using some solutions to reduce that effect (i.e. hands-free solutions), it is found that the driver is twice likely to miss traffic signals as per stated by (Strayer et al., 2004). Additionally; the driver is found slower reacting to the change in traffic patterns when being engaged in a cell phone conversation (Patten et al., 2004) and (Strayer et al., 2004).

Strayer et al., (2003), Piechulla et al., (2003), Redelmeier and Tibshirani, (1997) and Strayer and Johnston, (2001) discussed the impact of the safety the driving operation, which is found compromised while using the cell phone during driving based on statistics. For example (Redelmeier and Tibshirani, 1997) found that 24% of the 669 individuals involved in accidents during the study period had used their cell phones during the 10 minutes preceding the accident.

The biomechanical interference effect on the driving performance, such as catching the phone and dialing numbers, was found miner compared to the verbal task effect as the mental load is considered relatively high due to processing of information while conversating (Alm and Nilsson, 1995), (McKnight et al., 1993), (Patten et al., 2004), (Strayer and Johnston, 2001) and (Törnros and Bolling, 2005).

However, Lai et al., (2001) and Strayer and Johnston, (2001) studies showed that the passive verbal tasks, which do not require high mental load due to processing of information such as listening to radio, were not found to interfere with the driving task. While the active verbal tasks, such as conversation using hands-free of cell phone even as listening to a partner, were found disrupting the driving performance.

Patten et al., (2004) and Törnros and Bolling, (2005) found that, the difficult and complex conversations are more possible to have a negative effect on the driver distraction. Which makes the conversation is more important than the type of used cell phone.

In two studies (Rockwell, 1988) and (Zwahlen et al., 1988), it is suggested that to consider the driver is unpaired to go without roadway information for more than two seconds, which is called by the 2-seconds rule.

(Klauer et al., 2006) claimed in a study, on the in-road driving, that the driver eye glance behavior analysis indicates that the total eyes-off-the-road duration of greater than 2 seconds are found significantly increasing the crash risk.

Such research activities led to establish the safety guidelines for designing in-vehicle systems with focus on visual attention, for instance that an average of 2.7 glances and a total of 4.10 seconds fixation time are the maximum values allowed when driving at 30km/h as per resulted by (Lee et al., 2005), or that glances to displays should not be longer than 2.5 seconds as per (Aguiló and Fumero, 2004) or 1.5 seconds in (Wierville, 1993) research results.

Some studies were examining some possible interactive technologies for reducing the visual perceptual load. Cavedon et al., (2005), Gellatly, (1997), Harbluk and Noy, (2002), Trbovich and Harbluk, (2003) and Åkesson and Nilsson, (2002) found that the speech recognition and text-to-speech technological solutions are reducing the visual demands.

(Cavedon et al., 2005), (Gellatly, 1997) and (Harbluk and Noy, 2002) demonstrated the benefits of in-vehicle systems based on the eyes-free or hands-free technological solutions (Fig.2.3).

Which led to a common assumption regarding the speech-based interaction that it is not distracting the driver as it is not required to take the driver's eyes off the road.

Fig.2.3. Hands free solution

(Trbovich and Harbluk, 2003) and (Åkesson and Nilsson, 2002) studies stated that the voice-based solutions are not totally effortless, and it has potential to place cognitive demands on the drive with mind-off-road as a consequence. Despite of the being a good alternative, the speech-based interfaces were being under debate by divided opinions, since growing evidence suggest that systems with speech technology impose cognitive load on drivers that can affect driving performance. Another approach pointed out as an eyes-free method of interaction is gestures as illustrated by (Alpern and Minardo, 2003) (Fig. 2.4).

Fig. 2.4. Gesture controlling entertainment systems

2.4.1. Evaluating driver attention

A rapid start-up of the in-vehicle systems development phase is noticed as it has been under study by many researches to conduct simulated driving.

Some benefits are noticed for the simulated driving studies which provide precise control over all elements to create identical and repeatable scenarios. In addition to allowing researchers to analyze risky scenarios without compromising the participants personal safety. Therefore, simulated driving is often used to design and evaluate scenarios that would not be feasible or ethical in real driving, whether it is in a controlled driving setting or in a real traffic driving setting. As per stated by (Zajicek and Jonsson, 2005) simulated driving is beneficial in areas where controlled driving and real traffic driving are limited; making simulated driving a popular option in safety research programs.

Until 2010, only seven studies, (Aguiló and Fumero, 2004), (Airaksinen, et al., 2004), (Tijerina et al., 2000), (Hancock et al., 1999), (Hancock et al., 2003), (Lee et al., 2001) and (McElheny, 2005), were conducted on the controlled driving settings. Which gives an indicator of the possibility that test tracks or other closed circuits are not considered to be worth the effort or simply do not bring enough added value along.

Investigating the seven studies reveal that the geographical place is limited to only five places; two studies are conducted in places related to universities. Which indicates that experiments in controlled driving is troublesome to arrange compared to the added value in reference to simulated driving or that the controllability does not make it up for the safety issues that real driving involves.

The investigated studies do not argue for the choice of controlled driving, and this raises the question, whether this driving setting really is worth the hassle. Whatever the case, this finding sets the stage for an examination of the three driving settings that involve some version of driving.

A critical issue in this regard is the ability to create comparable scenarios in simulated driving and real driving. The limitations in simulated driving and controlled driving do not imply that these methods cannot be used to gather useful information. As stated by (Goodman et al., 1998), each of them has a place in safety research, particularly as a means to minimize safety hazards in exploratory research.

2.4.2. Measuring driver attention

Indirect measures are usually applied to assess safety and attention of drivers due to complexity of definitions and criteria of safety and attention. That is why some studies such as (Alm and Nilsson, 1995), (Broy et al., 2006), (Hulst et al., 2001), (Lai et al., 2001) and (Lee et al., 2001) commonly used measures of driver distraction related to secondary task interaction by primary task measures such as lateral control (e.g. measurement of lane keeping performance) and longitudinal control (e.g. speed maintenance).

Therefore, it is quite common to make inferences, such that higher driver workload when interacting with an in-vehicle system implies greater lateral movement and more frequent lane exceedances. It is interesting to note that a measure such as the number and length of lane exceedances during in-vehicle interaction is not considered primarily safety-relevant by everyone.

Cnossen et al., (2000) and Liua and Lee, (2006) studies argue that if there are no other traffic users nearby, if the lane exceedance is small or of short duration, or if the lane exceedance or speed reduction reflects the driver's strategy for compensation and reducing workload during concurrent task execution, there is no safety implication at all.

One interesting fact contradicting the previous studies is 11 research which showed that, based on the accident research and statistics, distraction related crashes are more likely during good conditions, i.e. in daytime, good weather, moderate traffic density, when the drivers think everything is fine.

Because of the importance of vision in driving the driver eye glance behavior measures (Fig. 2.5) are often used in several research activities such as (Aguiló and Fumero, 2004), (Green, 2001), (Klauer et al., 2006), (Lansdown, 2002) and (Mayer et al., 2002). Eye glance behavior is often measured by the glances a driver makes to a specific in-vehicle systems while driving. As an example, the number of times the driver glances away from the scene view to look at the display and the length of these glances (Aguiló and Fumero, 2004).

Fig. 2.5. Driver eye glance behavior measuring solutions

Eye fixation is typically considered as glances over 0.5 seconds. Green, (2001) stated that the eye fixation is often used as an indicator for to which objects the driver's attention is directed. While measures of eye glance behavior, in association with lateral control and longitudinal control, are used as detectors of general withdrawal of attention, it does not necessarily say anything about the selective withdrawal of attention that might be associated with in-vehicle systems. This is especially the case for in-vehicle systems that do not demand visual resources, such as speech-based interaction systems.

During performing the driving tasks, the driver can keep eyes on the road and hands on the steering wheel while serving the fundamental conditions for lane keeping and speed control. However, the mind might be somewhere else than on the driving task. Therefore, other measures are utilized such as reaction time and car following performance, as a method to measure some selective withdrawal of attention based on the driver's ability to react to external stimuli being interacting with the in-vehicle system.

Studies with reaction time are typically conducted in environments, where driving conditions, if any, such as road traffic, traffic lights, signs, and pedestrians are non-existent or controlled. The results of the classification indicate that, whether how people drive, how to measure driver attention or whether it concerns causal relationships between in-vehicle systems and driving performance, much of the research contribute to an understanding of a fairly new research field.

Katz et al., (1997) stress the importance of agreeing on a set of measures as the most important and predictive ones to be used as guidelines for engineers. Without agreement, engineers cannot verify claims that a specific design is safer to use or more suited for secondary task interaction.

In this regard, different rules and guidelines have been developed to accommodate engineers. Although researchers, roughly, agree on a set of metrics to measure attention by, they do not necessarily agree on how the rules should be defined. For instance, it is interesting that widespread measures, such as lateral control and longitudinal control are not outlined in the literature.

In addition, Green, (1999) introduced the 15 second-rule that states that the time allowed for completing a navigation system task involving manual controls and visual displays when the task is performed when not in motion, should be 15 seconds. However, Tijerina et al., (2000) have disputed the applicability of this rule, since the plausibility of accurately determining whether a device adheres to the rule is limited. Furthermore, Salvucci et al., (2005) states that the rule ignores many clearly crucial factors such as conflicting modalities between interaction and driving.

2.5. Multi-tasking vehicles cabins upgrade time-line

US Army population databases; which are created between 1960's and 1970's; were used as the base of anthropometric sources for the agriculture tractor design standards (SAE International, 1989, 1994). Thereafter; Hsiao et al., (2005) updated civilian population databases are developed showing the large variation in body dimensions between the army and civilian sources. Which makes very demanding issue of improving tractor designs based on the civilian agriculture workers and making it more specific toward workers actual dimension (i.e. Asian different than European, Male operators versus Female operators).

Back to the beginning of 18th century when it was the first time to discuss the importance of avoiding unnatural postures of human body during work performance. Basic guidelines and recommendations came out in the published scientific literature stating the "Good" and "Healthy" workplaces, while the off-road vehicles cabins are not an exception. Starting from

Moody, (1981) for adopting ergonomic set of values in designing a hand tool. Later; Barron et al., (2005); showing the importance of fitting every design to the human. Hasdoğan, (1996) added the idea of various assessments of the ergonomic thinking not only to the early design stages but for all the product life cycle.

Accumulated researches literature presents the importance of the ergonomics in workplaces design and its contribution in increasing the efficiency and safety of the operator by reducing the exposure to operation's hazards.

For ergonomic design; Charytonowicz, (2000) suggested that; spaces should be designed taking into consideration that it should fit for usage of living and functioning humans more than just being a piece of pure art, therefore; a better understanding for human operator needs and behaviors are required in order to optimize the design in more efficient and productive way.

Attaianese and Duca, (2012) proposed the need of comprehensive method for ergonomic design of indoor and outdoor spaces, which can be described as surroundings or environments in which human shall function inside. Such as a cabin of vehicle can be described in terms of architectural space, including many additional systems, the working environment of the operator may distract him\her from performing main tasks he\she is assigned for rather than supporting a safe operation. It is all depending on how the designers of cabins and production operations would define their main contributing factors to a successful, productive, and safe operation.

2.6. Operator – workplace interface design in multi-tasking vehicles

Along beside the fast growth of vehicles market, introducing information systems to the vehicle cabin is became essential area of research and development. Starting from simple engineering solutions to aid the cruise control till the current working prototypes of autonomous driving vehicles (Fig. 2.6). However; the operator-workplace interface design development is always considered important from the safety and productivity perspectives, thus one of the main concerns for all semi-autonomous features in the literature is that humans are poor monitors of automation.

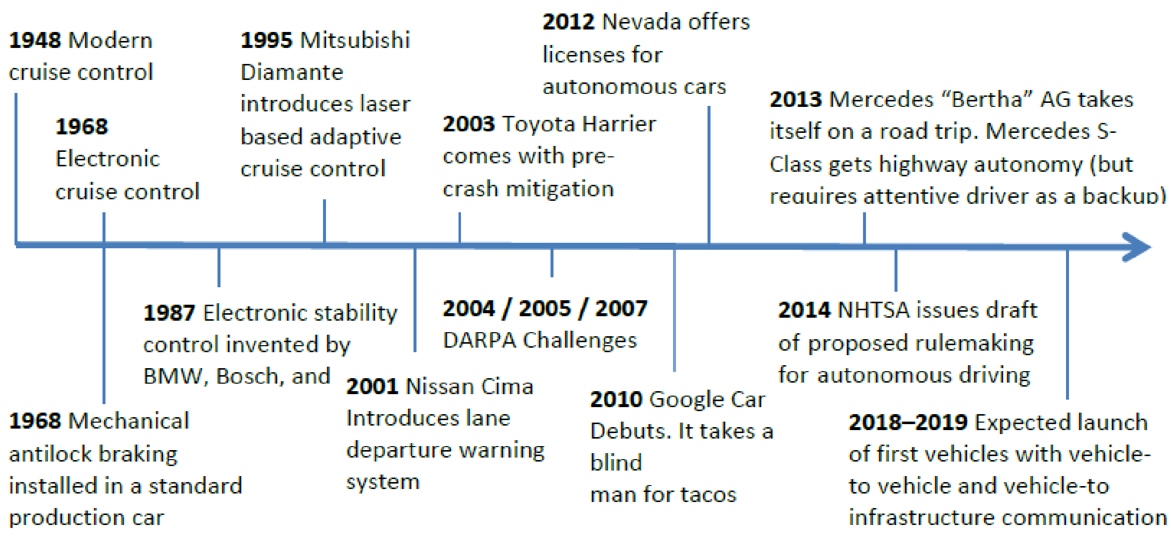


Fig. 2.6. Sixty-five years of automotive baby steps (Ross, 2014)

Off-road vehicles are not an exception in the presented paradigm. It requires more involvement of experts' opinions in design and operation issues.

Due to the operational nature of multi-tasking off-road vehicles, operators need to spend long working hours performing their duties; which increases the level of mental workload along working hours leading to human error might reduce the safety and productivity of planned operations. Li and Haslegrave, (1999) introduced similar conclusion of which the vehicle design should be human oriented in order to maximize comfort and ability to perform the driving task perfectly and safely by reducing the human error possibilities.

Nowadays increasingly agricultural machines are equipped with continuous measurement sensors i.e. measurement of soil resistance (Kroulik et al., 2015) to have more exact information on energy demand in order to contribute to the optimization of the production formula during performing his/her duties (i.e. the direction of windrowing based on soil properties). This means that many signals split the driver attention.

Many published scientific literatures discussed the definition of multi-tasking vehicles. The dominant properties of those vehicles are; found in literature; to be used off the road and demanding operator to perform more productive tasks alongside driving.

Most researchers agreed on the importance of the well seated position of the operator with very good visual ability in the human oriented vehicle design. "Good working posture" as a term has been introduced by European ergonomic and safety guidelines for forest machines, (2006) stating that, it is most proper for the performance of a specific task. Furthermore; defining factors associated with an acquired posture at performed tasks as follows: visual, reaching, manipulating needs, postural and biomedical loads. In addition to mentioned factors; the resulted posture is subjected to be affected by any constrains and obstructions imposed by the specific space which is limiting the ability to see, reach or exert force. However; the visual aspects might be affected by additional environment factors such as vehicle vibration, constrains and obstructions imposed by a specific cabin or vehicle geometry.

Published literature is reviewed to identify the recommended dimensions of seven types of controls (i.e., rotary switches, toggle switches, rocker switches, knobs, push buttons, hand levers, and steering wheels) and suggestions for labelling and placement of such controls.

However; Drakopoulos and Mann, (2006) research results showed that there is sufficient evidence to conclude that the controls being used in modern tractors are consistent with the design recommendations found in the literature. Of the recommended dimensions, the least conservative values were chosen for separation distance.

This is an indication that space is a premium inside a tractor cab. Most of controls (95%) are labelled using either a symbol or text, but there is a tendency to use symbols rather than text. Most controls (89%) are located by which it can be operated using the driver's right hand, however, only (75%) of controls were located within the functional reach envelope (i.e., 750 mm from the seat reference point). It is speculated that space may be a limiting factor due to the large number of controls required to operate modern agricultural equipment.

Such readings in the previous researches are resulted from accurate measurements. Utilizing such results will support the design process of tractor cabins. However; such designs still need further analysis in terms of productivity and usability in specific agricultural operations, due to the dynamic nature of agricultural operations and the accumulated fatigue along working hours.

2.7. Operator behaviours observation

2.7.1. Driver glance behavior

Birrell and Fowkes, (2014) conducted a comprehensive study regarding the glance behaviors when using an in-vehicle smart driving aid: a real-world, on-road driving study. It will be beneficial to be observed and compared to the off-road vehicles driving as where applicable.

The study raised the challenge for diverse information systems; implemented in-vehicle for different purposes; in terms of benefit analysis and distraction effect on the driver, providing a real-time tool to monitor driver's interaction with those systems and focusing on driving safely task.

The induced system in the mentioned study is establishing for common conditions while operating an off-road vehicle and being interacting with dashboard controls, side or tool panel and interactive multimedia equipment inside the cabin.

The study summarized key factors to be taken into consideration keep on reasonable balance between its usability and workload issue of the driver and minimizing the distraction mount coming from usage of information systems.

The issue of driver distraction is a very difficult factor to quantify, firstly because it can take different forms (visual, cognitive, physical etc.), but also measuring distraction itself is almost impossible. But still it could be represented via certain techniques to infer distraction which range from self-completed questionnaire, peripheral detection tasks, or measuring the time taken to complete a cognitive task.

Experiment description:

The important part of the study is the followed methodologies and basis of the study which is conducted on total number of participants of 40 driver from different genders and driving experiences. All participants went through predefined procedure for the experiment, i.e. driving scenario adopted (Fig. 2.7), speed limits and target time of finishing the experiment.

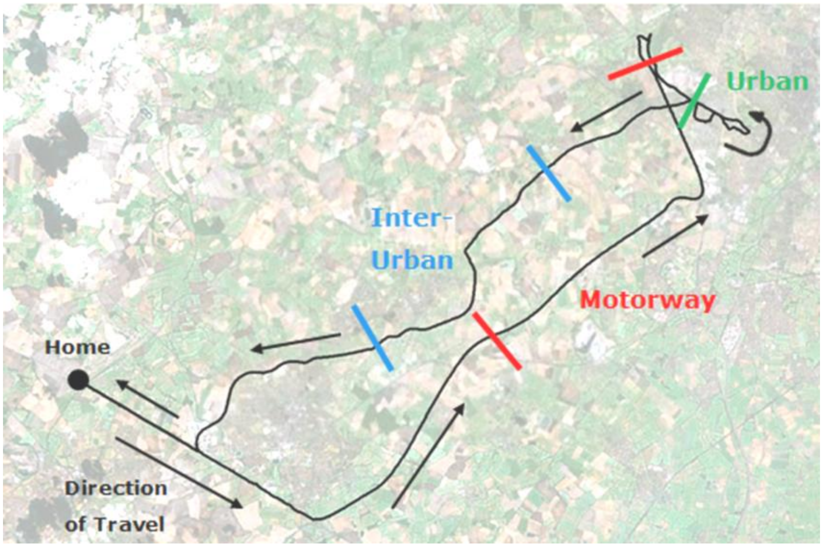
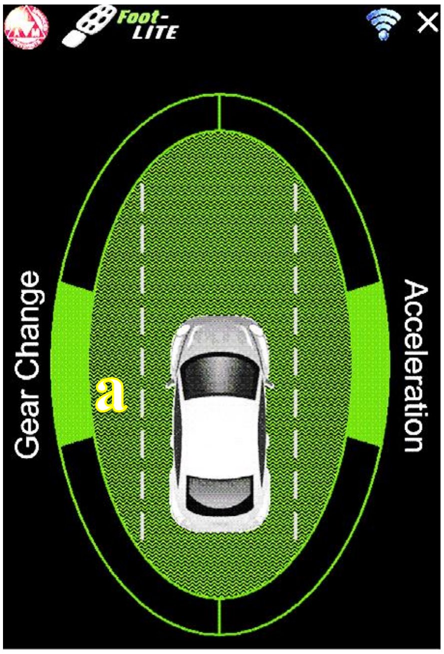


Fig. 2.7. Driving scenario adopted

The study utilized a smart driving system developed for a UK project called Foot-LITE (Fig. 2.8). The system developed aims to bring information on safety and fuel efficiency together on a single, integrated, adaptive interface.

Foot-LITE provides the driver with feedback and information on smart driving behaviors in the vehicle, in real-time via a visual interface presented on a Smartphone. The smart driving advice offered is based on the analysis of real-time information related to vehicle operation and local road conditions, with data being collected via an adapted lane departure warning camera, the vehicles On-Board Diagnostics (OBDII) port, as well as 3-axis accelerometer and a Global Positioning System (GPS) module.



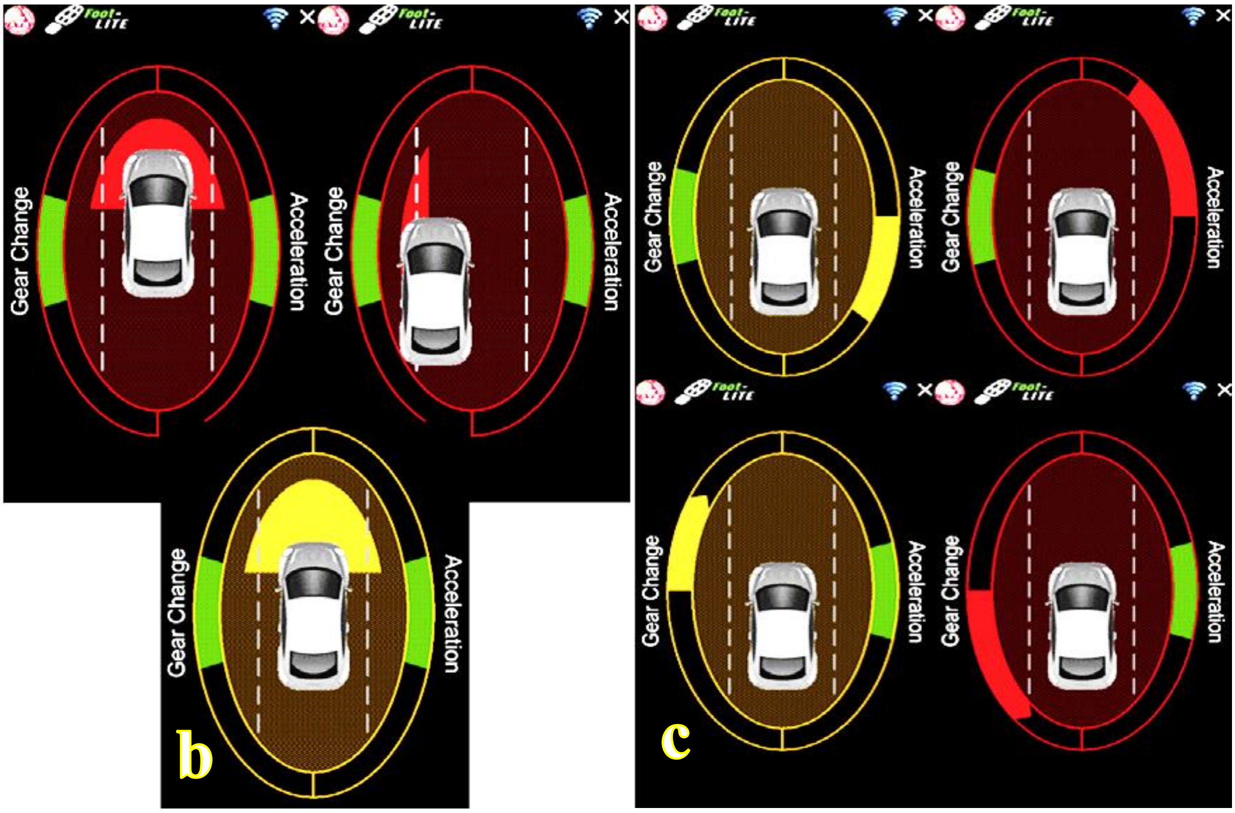


Fig. 2.8. Example screenshots from the Foot-LITE Smart driving advisor

Only one ‘oval’ is ever presented on the In-vehicle information system (IVIS) at any one time, but all aspects depicted can change in real-time and in combination.
Fig. 2.8, a– default green display.
Fig. 2.8, b– top-left to bottom – headway warning, lane deviation warning, and headway caution.
Fig. 2.8, c– top-left to bottom-right – braking caution, acceleration warning, change up caution, change down warning.

In-vehicle smart driving information presented to the driver in real-time were:

- Headway: A visual representation of time headway was presented to the driver as a cautionary threshold (shown as amber in Fig. 2.8, b) when the driver was less than 2 s to the car in front, and a warning threshold (red) when below 1.5 s. When the driver was greater than 2 s, or when headway information was not presented to the driver (i.e. below 15 mph or headway confidence was not sufficient) the display shows as the default green.
- Lane departure warning: A red warning was given to the driver when they deviated from their lane (Fig. 2.8, b). For this experimental setup the lane deviation threshold was set to be very sensitive, i.e. when the driver was close to the lane lines a warning was displayed, as well as when having left their lane. There was no cautionary advice for lane departure warning.
- Gear change advice: The bottom half of the picture in (Fig. 2.8, c) shows the gear change advice offered to the driver, with the amber arrows suggesting either a single gear change up or down in a sequential manner. Red arrows indicate gear either a block change (2nd

to 4th gears for example) is preferable, or a single shift if high power demand is needed. Once the driver changes to the recommended gear this section of the HMI will revert to the green default.

- Acceleration and braking: As presented in the top half of picture in (Fig. 2.8, c) braking and acceleration advice is offered to the driver to limit excessive acceleration, and to try and encourage a smoother speed profile. Again cautionary (amber) and excessive (red) warnings are given.

In addition to what mentioned above, video recording cameras and special software (JWatcher which is a powerful tool for the quantitative analysis of behavior) are used for further analysis of data extracted regarding the driver's eye and head tracking.

Critical target cases are defined and controlled (i.e. looking to sided mirror is considered when it happens via head movement OR eye movement).

Three dependable variables are defined for the study:

- Glance frequency: absolute and percentage of glances to a certain location.
- Glance duration: average, maximum and percentage of time spent at each location, and number of glances greater than 2 seconds.
- Glance transitions: percentage of glances to/from each location.

The three dependable variables are similar to the main variables selected to obtain the results of this research regarding the operator's focusing scheme change along working hours inside multitasking vehicle.

2.7.2. Driver state monitoring systems

A study conducted by Gonçalves and Bengler, (2015) claims that Highly Automated Driving (HAD) will be commercially available in a near feature, yet human factors issues like the influence of driver state can have a critical impact in the success of this driving paradigm and in road safety. It is very likely that Driver State Monitoring Systems (DSMS) will play a bigger role than they have played so far. However, with this new driving paradigm shift is important to select highlight what is transferable from the previous systems. Due to lack of driving task engagement, driving performance metrics are no longer viable, creating opportunities for other approaches like detecting non-driving task engagement or fatigue countering behaviors. Eye based metrics will remain important.

Human Factors in Automated driving (HFAuto) is a European project aiming to clarify the impact human factors has on Highly Automated Driving (HAD). In HAD an automated driver controls the vehicle's longitudinal and lateral control, while the human driver is only required to resume control if the vehicle requests due to system limitations. The novelty of this concept is that it assumes the driver is engaged on non-related driving tasks and does not enforce supervision, creating a significant different driving experience.

Driver State Monitoring Systems (DSMS), in its essence, are systems that collect observable information about the human driver to assess driver's capability to perform the driving task in a safe manner. DSM concept is often addressed in other terms like: DIM (Driver Impairment Monitor (De Waard et al., 1999), DIMS (Driver Inattention Monitor Systems) used in (Dong et al., 2011) and is more generic than Driver Vigilance Monitoring (DVM) from (Boverie and Giralt, 2008). Applications of this technology can be used for active safety, adaptive Human Machine Interface (HMI), and annoyance reduction for false positive notifications (Opperud et al., 2005). With the arrival of HAD, these systems gained more relevance due to the need for understanding and adjusting to the driver conditions. Unfortunately, DSMS has been mainly isolated systems, custom designed for single purpose application such as distraction detection (Opperud et al., 2005), (Swingler and Smith, 1996), (Fletcher et al., 2005) and (Tango and Botta, 2013) or drowsiness detection systems (Boyraz et al., 2008), (Hernandez-Gress and Esteve, 1997) and (Rauch et al., 2009).

The major contribution of Gonçalves and Bengler, (2015) study is to provide an overview on DSM from a HAD point of view. There are several DSMS reviews available (Dong et al., 2011), (Hernandez-Gress and Esteve, 1997) and (Horrey et al., 2012), but none of these aims to transfer this knowledge to HAD context. Furthermore, it also points some directions DSM systems need to take to meet HAD requirements.

No universal definition of what is considered driver state, the term is often used in a loosely manner from psychologists and engineers’ communities. In general, driver state refers to a set of conditions that affect the driver in a specific instance. Drivers in an optimal state do not suffer from any condition. For this reason, DSMS are designed to host modules that identify specific conditions. These conditions fall into two main categories: distraction and fatigue (Dong et al., 2011). These categories can also be considered equivalent to HAVEit’s driver state attention and alertness components (Rauch et al., 2009).

There are other known conditions that do not fit in any of previously mentioned categories. For example, intoxicated (alcohol or drugs) drivers have; considerably; more difficult to cope with the driving task. Although it is questionable if even in a HAD context driver could be allowed to engage under such condition, its detection without driving performance (due to HAD) or blood analysis makes the diagnosis impossible or very intrusive. For this same reason, forms of fatigue such as physical fatigue originated from exerting activities prior to the travel could also be hard to detect without heart rate or questionnaires. Therefore, the study is only considering to this review conditions whose diagnose technology depends on non-intrusive and direct measurement techniques.

Distraction:

Distraction is considered as an attention shift away from driving related tasks, by allocating resources need for the driving task to non-driving tasks. Numerous factors endogenous and exogenous factors to the vehicle can happen (exhaustive lists are mentioned in (Stutts et al., 2003) and (Stutts et al., 2005)). When distracted, the driver loses awareness of the current driving situation translating into vigilance decrements and higher collision risk. This study will consider the following distraction categories: visual, auditory, mechanical, and mental. These categories aim to represent the predominant resource being used, according to the multiple resource theory.

In (Tab. 2.2) are the most relevant head/eye-based metrics obtained from eye-tracking systems. Visual distraction is usually associated to looking away from the road scene, for example read information from the IVIS. From the eye behavior process, the gaze is the dominant sub-process used to detect distraction.

Eyes-Off-Road (EOF) duration is the most used metric detect distracted drivers, the higher the time the lower the driver's awareness due to its simplicity to check if the driver was looking to the road (Young et al., 2008). In studies where researchers create virtual areas of interest (AOI), then glance's space and time dimensions allow a more detailed analysis than the binary approach of eyes on/off the road. Glance Pattern refers to sequence of AOI fixated by the driver. AOI sequence allows predicting driver's intentions, for instance mirrors checking before overtaking another vehicle. Visual task engagement is also possible to detect, by comparing with normative pattern. Mean Glance Duration highlights the time spent on each AOI, which is like the earlier Glance Patter utility enables the detection of disproportional gaze time allocation as an indicator of task engagement/distraction.

Pupil Diameter has been reported to be sensitive to Cognitive (i.e. mind wandering) and for Auditory (i.e. reacting to cell phone ring). Tursky et al., (1969) designed an experiment with tasks and levels of difficulty. The pupil reacted consistently by allowing distinguishing between different task and the level of difficulty.

Mechanical distraction is related to the driver's body posture during the driving task. For instance, a driver facing the passenger seat reduces his vision of the road center and is in a non-ideal position for resuming control of the car in the case of a sudden event. Head direction has been used in HAVEit as a variable to assess the driver distraction (Rauch et al., 2009).

Table. 2.2. Set of metrics associated with distraction detection.

Type of distraction	Reference metrics	References
Visual	Glance Pattern	(Angell et al., 2006)
	Mean Glance Duration	(Victor et al., 2005)
	Eyes-Off-Road Duration	(Liang et al., 2014)
Auditory	Pupil Diameter	(Tursky et al., 1969)
	Blink Frequency	(Hargutt and Kruger, 2001)
Mechanical	Head direction	(Rauch et al., 2009)
Cognitive	Pupil Diameter	(Tursky et al., 1969)

Fatigue:

The Fatigue category includes the cases where human drivers experience lack of motivation to engage in the driving task, instead they seek more comfortable goals to rest. Like in vigilance tasks over relatively lengthy periods, there is a natural vigilance decrement occurs however is also followed by drowsiness signs and perception of being tired. Fatigue is treated separately from other forms of inattention because:

1) It not only reduces situation awareness but also affects the central nervous system and consequently mental and motor coordination (Shinar and Gurion, 2007) and (Lal and Craig, 2001);

2) Has a higher temporal window associated with minutes or hours (Rauch et al., 2009).

For this research, the scope is limited to passive fatigue. This type of fatigue is characterized by being the indirect product of the human driver's exertion of a set of tasks whose demands are low, monotonous, or repetitive (Saxby et al., 2013). Which makes results used out of any physical fatigue or mental active fatigue.

(Tab. 2.3) presents a list of metrics; commonly; used for detecting fatigue. The eye-based signals are useful because of the existed deep nervous connection between the brain and eye (Saxby et al., 2013). These motor and sensor connections between both organs allow monitoring signals associated to fatigue that are not controlled consciously by the human. With the progress in image processing systems and camera technology, today is quite common to use eye tracking systems for obtaining many reliable metrics.

Table. 2.3. Set of measurements associated with fatigue detection

Type of metrics	Metrics	References
Eye based	PERCLOS	(Barr et al., 2009)
	EYEMEAS	(Friedrichs and Yang, 2010)
	MEANCLOS	(Friedrichs and Yang, 2010)
	AECS	(Friedrichs and Yang, 2010)
	Blink Frequency	(Friedrichs and Yang, 2010)
	Microsleep rate	(Friedrichs and Yang, 2010)
Behaviour based	Yawning	(Smith et al., 2003)
	Nodding	(Friedrichs and Yang, 2010)
	Slouching	(Senaratne et al., 2007)
	Eyebrow rising	(Jimenez-Pinto and Torres-Torriti, 2009)

While distraction eye-based metrics are focused on the gaze process, fatigue metrics rely on the eye-lid movement process. By observing the blinking behavior (Hargutt and Kruger, 2001), (Friedrichs and Yang, 2010) increments in frequency can be associated with reduced vigilance (Hargutt and Kruger, 2001). Blink metrics are usually defined with a minimum time acceptance (bellow the blinks are ignored due to noise data) and a maximum time from which is already considered a Microsleep. Microsleeps are inherently associated to fatigue so in this case also the increase represents a degradation of the fatigue condition. EYEMEAS (Mean Square Eye Closure), MEANCLOS (Mean Eye Closure), and AECS (Average Eye Closure Speed) metrics use raw eyelid behavior over medium size time intervals, providing an overview of that interval.

The most used metric is the PERCLOS (Percentage Eye Closure) present in projects from academia to commercial applications (Barr et al., 2009).

Eye metrics value is unquestionable due to the ability to obtain relevant data associated with fatigue in a nonintrusive way and enjoys a broad community acceptance. However, eye metrics also have considerable drawbacks. First, despite the progress in camera technology, detection, and tracking of eye-based features improvement in recent years, data remains a noisy. In the case of blink-based metrics it is particularly problematic because a non-detected eye may be interpreted as an eyelid closure. Glasses' lens can hinder the pupil detection. In real world conditions, sunglasses or body postures not facing the camera nullify any eye-metric based system.

Behavior based metrics are a promising source for information for detecting drowsiness due to a set of behaviors associated with drowsiness. One reason for this behavior change is the driver's perception of its condition and by changing the behavior to counter the fatigue progression. Other common goal is to change the posture to some more comfortable positions. These types of behavior can be classified as:

1) Postural adjustments,

2) Verbal exchanges,

3) Ludic activities, and

4) Self-centered (Rogé et al., 2001).

One of major advantage of these metrics is that it resembles the way a passenger looking to the driver would infer the fatigue. Because of this intuitive nature it allows synthesizing a rule-based system easily, for instance fuzzy based systems (Bergasa et al., 2006).

The performance of such behavior activities is person dependent, so when people perceive themselves fatigued they may do several of these activities. This also implies that even if the driver does not perform such activities he/she may be fatigue, so behavior-based metrics should not be used alone since they are not sufficient for detection. Another limitation is that each specific cue requires a specific detection algorithm, which considerably limits the detection capability due to practical reasons and restricts the cues to a set of generic ones.

2.8. Summary of literature review evaluation

No solid single definition for the mental workload has been reached by researchers, but it could be defined as the relation between demands resulted from various tasks to be performed on the operator and his ability to fulfill; with satisfactory; these demands. Sporrong et al., (1998) described the mentioned demands as multidimensional, as it involves tasks, operator and system demands together with other factors, accordingly; Sporrong et al., (1998) studies showed that the need for well fitted architectural space to the operator's dimensions is considered crucial, additionally; the mental workload level is found to be increasing with the time passing.

It became obvious how important and relevant is the ergonomic thinking inside the vehicle cabin design. However; as found in previous scientific literature; it is still considered very challenging to embed the ergonomic thinking into the vehicle cabin design according to many various aspects, therefore; many guidelines and recommendations are published to empower the design process of vehicle cabins and its different components with suitable ergonomic solutions.

The interesting results came out of the study showed that using the in-vehicle smart driving aid during real-world driving resulted in the drivers spending an average of 4.3% of their time looking at the system, at an average of 0.43 s per glance, with no glances of greater than 2 s, and accounting for 11.3% of the total glances made.

The main outcome relating to glance frequency from this study is that, including information system to the vehicle cabin did not reduce number of glances to the main roadway ahead, or to driving relevant in-vehicle tasks such as speed monitoring or checking mirrors, but simply increased the glances into the area of the interest.

One of the most effective ways to record driver distraction is by assessing glance behavior and recording the length of time that the driver spent with their eyes on several target locations. The introduction of an in-vehicle information system will inevitably lead to drivers spending some time looking at the display while driving. As described above this may not be a problem in itself; however, this allocation of visual resource and control panels should not be taken from the driving critical tasks such as looking at mirrors, the instrument panel and most importantly the road in front.

Despite the fact that selective withdrawal of attention or mind off-the-road is considered a major contributing factor of the attention failure, the general withdrawal or eyes-off-road is still considered more common, that is because of the importance of sight in driving task. Many studies (Klauer et al., 2006), (Lansdown, 2002), (Lee et al., 2005) and (McCarley et al., 2004) depended on information of the driver glance behavior gathering such as number of glances and fixation times in a variety of driving tasks. However, all of that studies concentration in the in-road driving studies, unlike this research in which the information is gathered in more complex operations in off-road environments. Therefore, to correlate the fatigue to the glance behavior of the operator, the most challenging environment is selected, which is the agricultural field.

In spite of the differences of research results and developed guidelines, it is obviously found that only a limited amount of information can be conveyed safely to the driver. As a conclusion, any design of new in-vehicle system, for in-road vehicle, must not overload the driver perceptually. Thus, if in-vehicle systems interaction can be designed such that it has only few glances and low fixation times, or simply has no interaction induced visual demands; it may very well increase safety while driving.

After an experiment conducted on many participants to use their gesture controlling entertainment systems while driving such as shuffling songs and set the volume. The gesture-based interface resulted fewer driving errors than the conventional interfaces. However; the difference was not significant. Conducting qualitative interviews after the experiment, the participants selected the gesture interface over the radio, due to the ability of keeping eyes and attention on the driving task. While these results are not found conclusive, they suggest gesture interfaces can be used as safely as a physical radio and seems to be a viable alternative for completing secondary tasks in the car.

In reference to the previous researches, it seems injudicious to conduct comparative studies of different in-vehicle systems, find that one induces substantially more lane exceedances and still declare such results irrelevant unless there happened to be a crash hazard exposure.

HAD concept tries to automate as much as possible the driving task, this way freeing the driver to engage in other tasks. Yet, the human driver still retains the responsibility to resume the vehicle control in situation where the automation cannot handle. The Take Over Request (TOR) process has many challenges that must be addressed to achieve the goal of allowing the driver to engage in other tasks and effectively support him to resume control in a safe manner.

One way to compromise the safety of a TOR process is to assume the driver is in a good status every time the TOR initiates. This process should not be set with fixed time buffers (Gold et al., 2013) but adjust the time buffer to the driver state.

In practice, this is an application of the knowledge produced in the context of manual driver, for instance fatigued drivers have higher reaction times.

DSMS have been relying; mainly; on eye-based metrics and driving performance. Eye metrics have more recently enjoyed the benefit of better technology, which has translated into more reliable measurements. In this sense it is expectable that they remain with similar role for this new generation.

Driving performance data absence is the major change in this field, providing reliable data even in situations where eye-tracking data was not available. This data does not totally disappear because it can still be useful for during the TOR process, for instance to detect if the driver can handle the transition. Without these emergency TOR use cases, the more common use case is to not have any driving performance available. It is expected that this can create an opportunity for other advancing other type of data for accessing driver state.

For distraction detection, a viable alternative could be monitoring the body posture. The freedom allowed in HAD can be used for less conventional body postures that could, along with head rotation indicator if the driver is deviating from what a normative driving posture would be.

Fatigue countering behavior has received yet little attention in DSMS. There is evidence that drivers under fatigue behave differently either by adjusting their body posture or by trying to interact with themselves (scratching face, covering mouth, rubbing eyes).

In reference to the reviewed literature, it is considered beneficial to investigate more in the change of operator behaviors along working hours inside workplaces during conducting several specific production operations.

Agricultural production operations are; generally; considered mental and physical efforts consuming activities. Therefore, it is beneficial to analyze some behaviors changes to represent how more difficult or risk a production operation could be comparing to other operations.

Off-road vehicles with multi-tasking functionality are considered more challenging work environments for drivers or operators. The fatigue and distraction effect are expected to be obvious which is making it easier to model the change of operator behaviors along working hours.

The operator's focusing scheme is the selected behavior to be studied in this research, such input will be valuable to the vehicle designs as well as to the operations design. Such behavior has an impact on HAD in the used artificial intelligent systems and DSMS design inputs to make the media used safer and more productive.

Based on the results achieved so far in the studied previous works, during the forming of the aims of the recent PhD work, it was a strong initiation for an experimental improvement for the human behavior inside off-road vehicles carried out to enhance the design process of the cabins, productive operations and manpower based on reliable and deterministic inputs.

3. MATERIALS AND METHODS

The present chapter is introducing the materials and their preparations which used in my research in addition to the engineering and scientific methods involved experimental measurements, characteristics, methodological knowledge, and description of the test systems to achieve the research goals.

3.1. Tobii equipment and software package

Tobii solutions were used to conduct the eye tracking and glance measuring of the operator inside the off-road vehicle cabin.

Tobii glasses 2 (Fig. 3.1) package was selected due to its mobility feature in addition to the powerful properties enable the operator to use it in the daylight and night in the field. A brief description of the package is illustrated in the figure below:

1- Eye tracker: consists of cameras, illuminators, and algorithms.
2- Scene camera: a camera is recording what the operator is looking at.
3- Illuminators: creates a pattern of near infrared light on the eyes.
4- The cameras: take a high-resolution image of the user’s eyes and patterns.
5- The image processing algorithms: find specific details in the user’s eyes and reflection patterns.
6- The eye position and gaze point are calculated using a sophisticated 3D eye model algorithm based on the inputs and configurations mentioned previously.

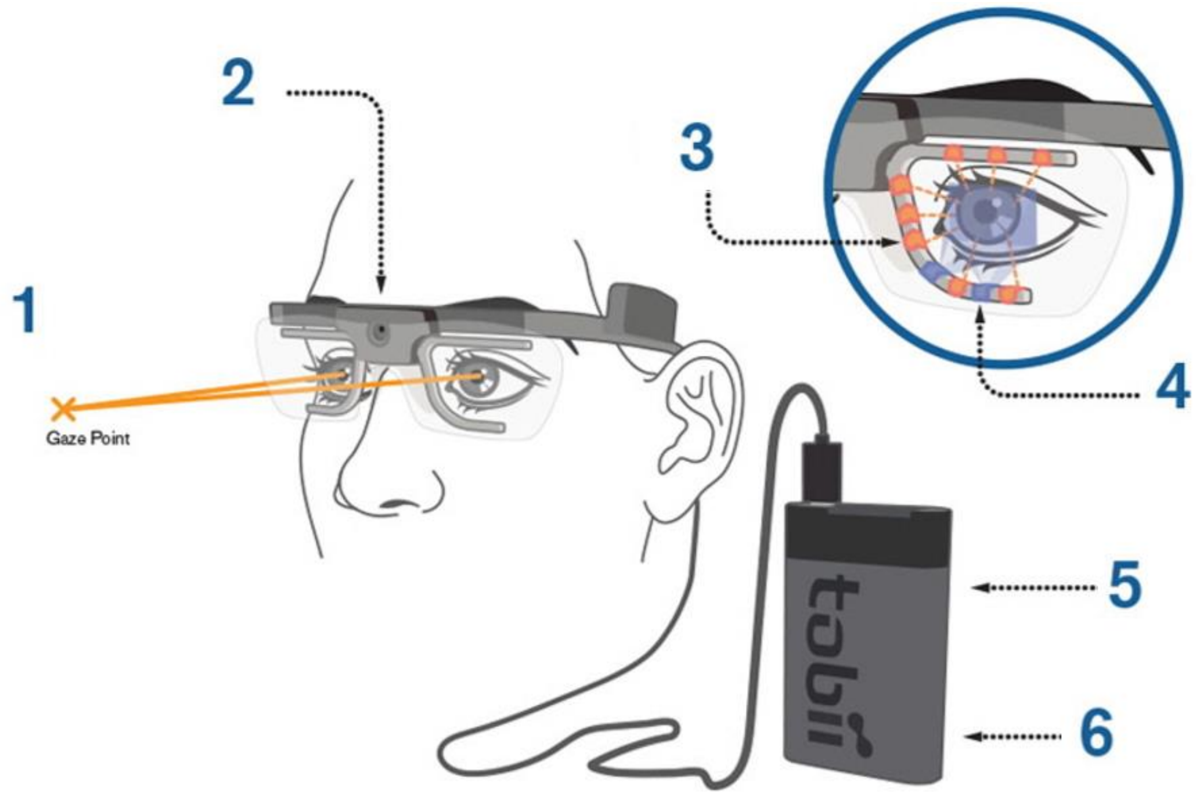


Fig. 3.1. Tobii glasses 2 package

3.1.1. Tobii Glasses 2

The glasses equipment (Fig. 3.2) is used to the purpose of obtaining the operator's focusing scheme from his/her real-time gaze analysis to predefined areas of interest. Which is feeding the research results with the main source of data regarding the target behavior to be studied.

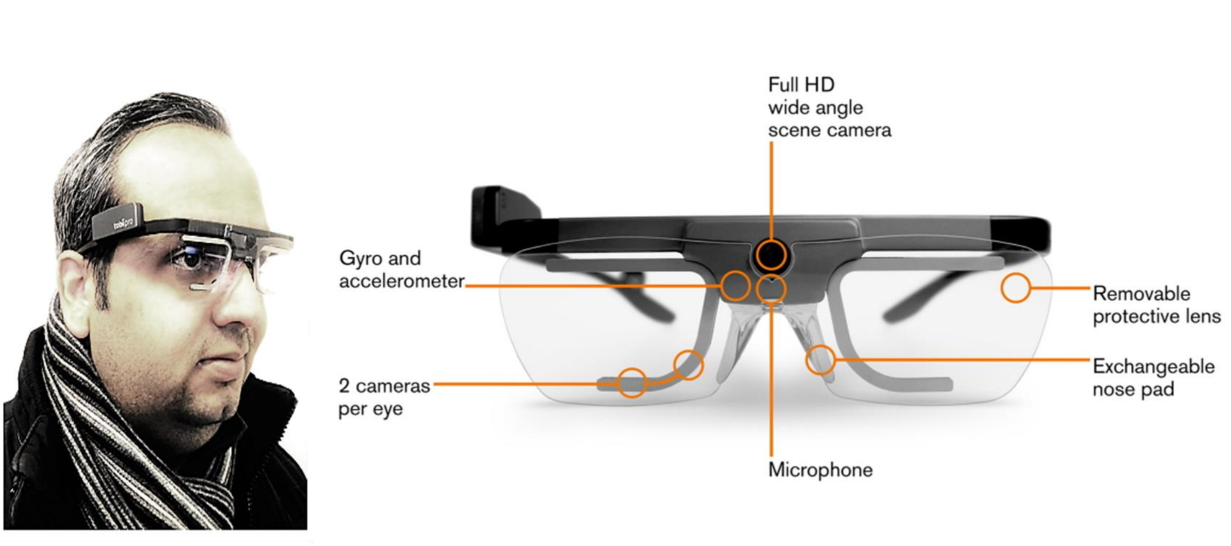


Fig. 3.2. Tobii glasses 2

To record eye tracking data, the Tobii glasses head unit must be fitted onto the test participant's head (like a standard pair of glasses). The system must then be calibrated separately for each participant. In the calibration process the test participant is asked to look at a Calibration Card held in-front of the participant for a few seconds. The researcher then starts the recording from Tobii Glasses Controller Software running on a Windows 8/8.1 Pro tablet or any Windows 8/8.1 or 7 computer. After the session, the researcher stops the recording and removes the head unit from the test participant. All interactions with the eye tracker (adding participants to test, initiating calibration, starting/stopping recordings etc.) are done through Tobii Glasses Controller Software.

3.1.2. Tobii controller software

The controller software (Fig. 3.3) also enables the researcher to view/hear the eye tracking session both in real-time (streamed through a wireless or wired connection) and after the recording. When viewing a recording, it provides for hearing what was recorded on the integrated microphone of the Tobii Glasses 2 Head unit, the participant's gaze point also appears as a colored dot on the scene camera video from the HD camera integrated in the Tobii Glasses 2 Head Unit.

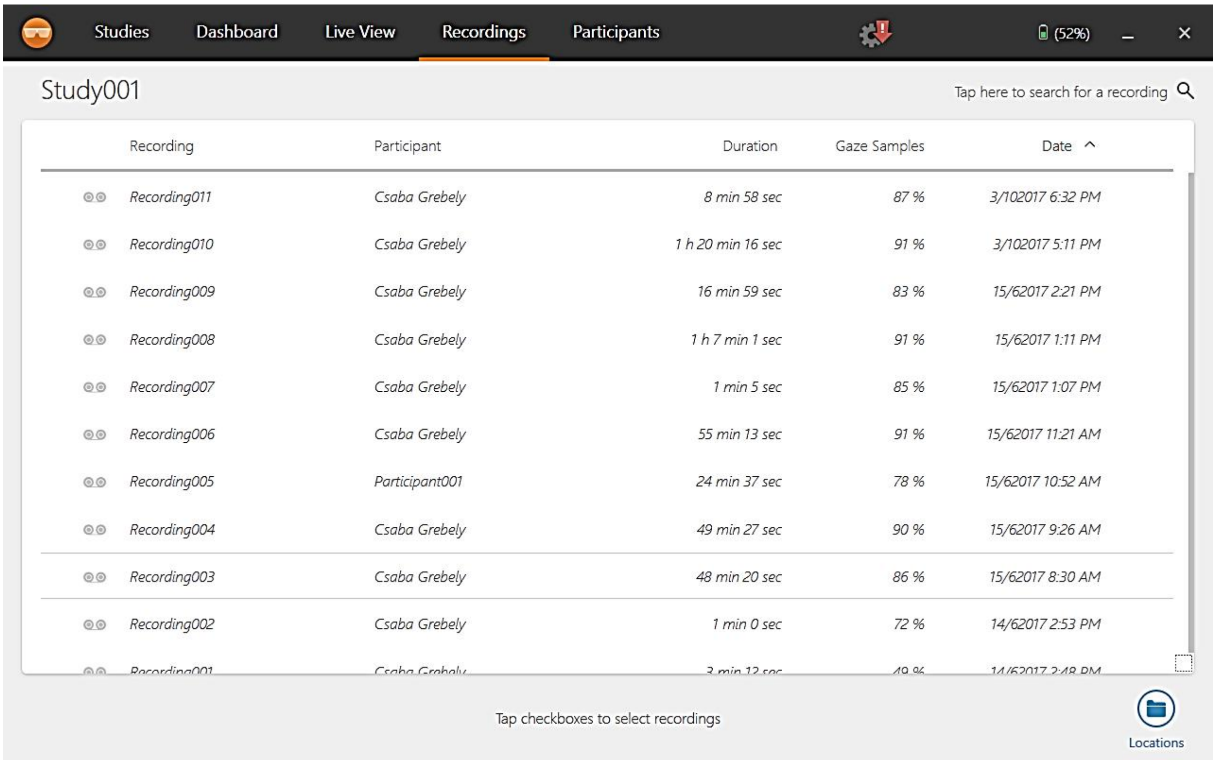


Fig. 3.3. Tobii controller software

3.1.3. Tobii Pro Lab software

The main processing tool of the operators' gazes is the Tobii Pro Lab (Fig. 3.4) which has a powerful post-analysis and visualization tools provide a full spectrum of qualitative and quantitative gaze data analysis and visualizations. Tobii Pro Lab logs events, defines areas of interest, calculates statistics, creates heat maps, and exports data for further analysis in other software.

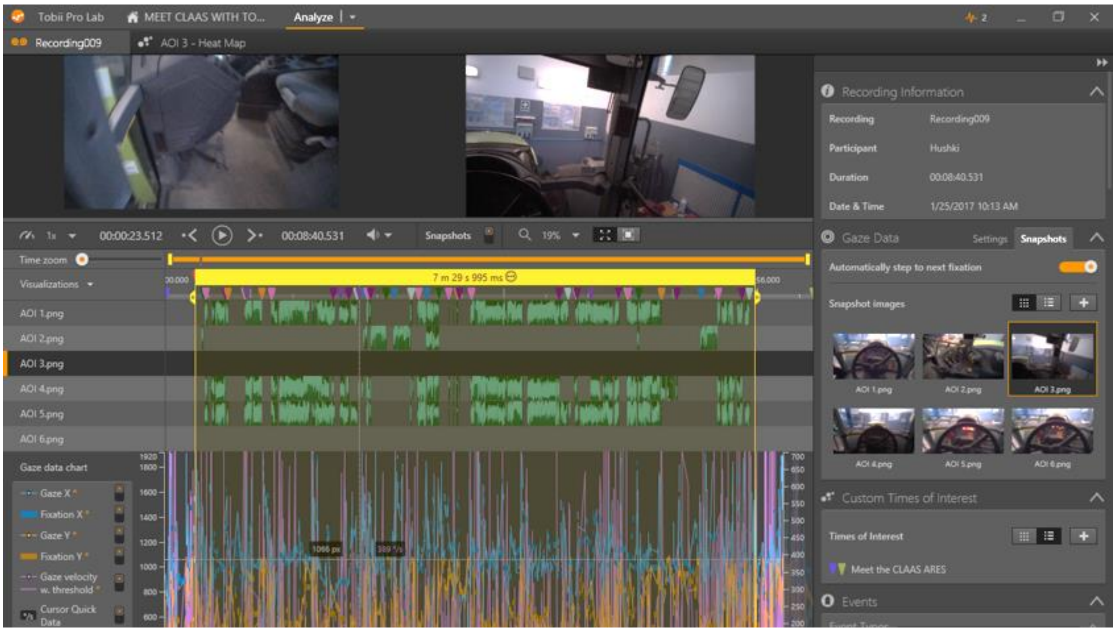


Fig. 3.4. Tobii Pro Lab – analyzer software

Tobii Pro Studio has three distinct types of fixation filters to group the raw data into fixations and Tobii Pro Lab uses one type of fixation filter to process the data. These filters are composed of algorithms that calculate whether raw data points belong to the same fixation or not. The basic idea behind these algorithms is that if two gaze points are within a predefined minimum distance from each other (Tobii Fixation and ClearView Fixation Filter) or possess a speed below a certain threshold (Tobii I-VT Filter), then they should be allocated to the same fixation. In other words, the user has kept the eyes relatively still between the two sampling points.

3.1.4. Areas of interest and reference snapshot

The area of interest is a concept and a Pro Lab tool that allows the eye tracking researcher or analyst to calculate quantitative eye movement measures. These include fixation counts and durations. Using this tool, the researcher simply draws a boundary around a feature or element of the eye tracking stimulus whether it’s a button on a web page or actor walking across a scene in a video clip. Pro Lab then calculates the desired metrics within the boundary over the time interval of interest.

3.1.5. Real world mapping and time of interest

The Real-World Mapping tool integrates into the Pro Glasses Analyzer, streamlining the coding process and dramatically reducing the analysis time. It aggregates and maps data from eye tracking videos to snapshots, allowing immediate visualization of the quantified data or extracting statistics. The powerful post-analysis and visualization tools provide a full spectrum of qualitative and quantitative gaze data analysis and visualizations provides for log events, define areas of interest (AOIs) during the selected time of interest (TOI) from the total recording time, calculate statistics, create heat maps, and export data for further analysis in other software.

3.1.6. Equipment technical specifications

Following are the technical specifications of the equipment which is used in the research in addition to the required software package used and its operational requirements.

Eye tracking equipment:

Eye tracking technique	Corneal reflection, dark pupil
Binocular eye tracking	Yes
Sampling rate	100 Hz
Calibration procedure	1 point
Parallax compensation tool	Automatic
Slippage compensation	Yes, 3D eye tracking model
Pupil measurement	Yes, absolute measure

Head unit equipment:

Material	Grilamid plastic, stainless steel, aluminium
Protective lens	Plastic, in 2 versions: clear and tinted

Interchangeable lenses	Yes
Nose pad	Grilamid plastic, interchangeable
Scene camera, video resolution	1920 ×1080 at 25 fps
Scene camera, video format	H.264
Scene camera, field of view	90 deg. 16:9 format
Scene camera horizontal and vertical FOV (approx.)	82 deg. horizontal / 52 deg. vertical
Weight	45 grams including protective lens
Frame dimensions (width ×depth ×height)	179 ×159 ×57 mm
Cable length	1200 mm
Visual field of view (frame obstruction)	More than 160 deg. horizontally, 70 deg. Vertically
Audio	Integrated microphone
Design characteristics	Light weight and discreet
Number of eye tracking sensors	4 sensors
Fixed geometry	Yes
Sensors	Gyroscope and accelerometer

Recording unit equipment:

Battery recording time	120 min
Battery type	Rechargeable 18650 Li-lion, Capacity: 3 400 mAh
Storage media	SD (SDXC, SDHC) card
Connectors	HDMI, Micro USB, 3.5 mm jack
Dimensions (height x width x depth)	130 x 85 x 27 mm
Weight	312 grams
Sync Port	3.5 mm jack (TTL signal)

Software packages used:

Recording and live viewing	Tobii Pro Glasses Controller	1.46.3420 (x64)
Data analysis and export	Tobii Pro Glasses Analyzer Software	1.49.4073 (x64)
Data recording and documentation	Microsoft Excel	Pro 2013 (x64)

Processing computer equipment:

Operating system	Windows 10 (64 bit)
CPU	Intel Core i5 6th Generation
Resolution	1024 x 768
Memory	8 GB

3.2. Methodology testing

3.2.1. Selection of operators

To the purpose of testing the method; one operator is selected to wear the eye-tracking equipment. The operator is mandated to spend several minutes inside the selected vehicle cabin to get familiar with the dashboard and equipment panels.

3.2.2. Selection of vehicle, experimental field and operation

CLAAS tractor (Model: ARES 567 ATZ) is selected to the purpose of accommodating the number of experimental trials (Fig. 3.5). This model has a covered workplace for the operator, which is helpful to control some of experimental conditions (i.e. temperature and humidity) keeping on the consistency of those parameters and conditions.

Fig. 3.5. CLAAS tractor (Model: ARES 567 ATZ)

Experimental trials for this part of research are conducted inside Szent István University Laboratories where the tractor is located. The operation part is limited to develop the operator’s focusing scheme while exploring the cabin contents of the selected tractor. Spending several minutes as a familiarization process, the operator is introduced to the notification panel, main control panel and the side control panel components.

For methodology testing part of the research, one operator is selected to wear the Tobii Glasses 2 equipment which is connected to the central device running Tobii Controller Software by which the calibration process of operator focusing is conducted and recording process is controlled.

The tractor used (CLAAS tractor (Model: ARES 567 ATZ)) is located inside Szent István University Laboratories. Primary areas of interested (AOIs) are defined inside the tractor cabin.

The operator is tasked to go through the calibration process, start the recording process and get in the tractor cabin for several minutes to get familiarized with the cabin components paying attention to the selected AOIs while receiving verbal illustration regarding each component.

Thereafter; the recording process is stopped, and the recorded video is processed by the Tobii Lab pro software using the automatic real-world mapping tool, heat maps representing operator's focusing scheme during the recording time are generated by the software, which leads to generate the statistic readings using MS Excel software.

3.2.3. Methodology testing procedure

The experiment is conducted on 3 phases (Fig. 3.6):

Phase 1: in which the consistency and similarity of the used work field and timing of operations will be ensured. Which applies as well for the experimental execution procedure. Operators are tasked to conduct the same operational procedures along trials. A calibration process for the Tobii glasses 2 is conducted via its dedicated software Tobii glasses controller software. Each operator profile is stored in the software, the software and the equipment have the capability to keep on each operator's profile stored, and no recalibration is required to start the next experiment or to restart the recording during the same experiment in case of interruptions.

Phase 2: in which the execution of the experimental trials and data gathering are conducted. The operator is requested to wear special Eye-tracking Tobii glasses 2 providing the operators vision area and defining the point of focusing. Connected to the central station, the recording time is synchronized for all resulted video records.

According to the experiment execution procedure, several areas of interest will be added to matrix storing the representing scheme [M], each element in the matrix will store the accumulated time of operators' glances (gaze) to that AOI [AM].

Phase 3: in which data analysis and discussion are conducted. The video records are studied and analyzed by the research team to decide and document all none beneficial periods that includes abnormal behaviors or reactions to a random external inducer of the operators describing the reason of period exclusion.

Thereafter; the resulted data from the used eye-tracking glasses technology after exclusion procedure is represented in the matrix [AM].

Elements of [AM] are integrated at selected periods of working hours (i.e. at the end of each working hour or based on the nature of the operation) to produce the matrix [IM]k. where k is the selected period number from 1 to K times.

Along working hours, the change of [IM] with increment of k with increment of l will be placed on a graph showing the change of the operator's focusing matrix. Which is the target behavior studied for each operator along several experimental trials.

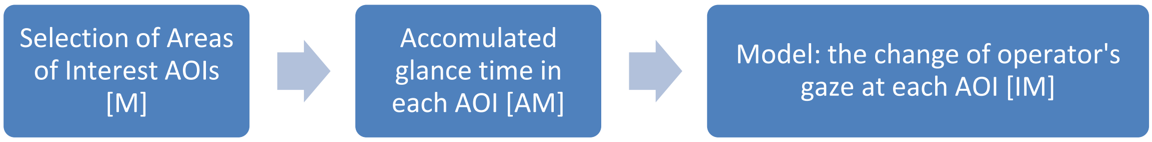


Fig. 3.6. Generating the Change of Operator's focusing scheme along working hours

The used material for the methodology testing (Fig. 3.7) was a simple hand-held tablet running MS Windows 8.1is used to run the Tobii controller software to operate calibration process for the Tobii glasses user and to monitor the actual glance behaviour of the operator during the recording process.

In addition to the portable recording unit of Tobii glasses is handling the video recording task, all recorded videos are stored on an integrated memory card to be used at the video processing stage using the Tobii Pro Lab (the analyser software package) which is run on another laptop device with a powerful processing capability meeting the Tobii Pro Lab software package hardware requirements.

Fig. 3.7. Material used for the methodology testing

3.3. Field works

Outdoor experimental trials are conducted on different agricultural fields using different tractors and combined tools.

3.3.1. Windrowing operation

Windrowing agricultural operation is selected to be the studied operation in this research to produce the model of the change on operator's focusing scheme along working hours. After hay cutting in the agricultural field, windrowing operation is conducted to sort hay into lines in the field. The operation is conducted by specific tools attached to tractors generating hay lines to prepare for the hay baling operation. To the purpose of this research, the used attached tool to the CLAAS tractor (Model: ARES 567 ATZ) is CLAAS LINER 450T (Fig. 3.8).

Fig. 3.8. CLAAS LINER 450T used for windrowing

CLAAS tractor (Model: ARES 567 ATZ) is selected to the purpose of accommodating the experimental trials of windrowing operations. This model has a covered cabin for the operator, which is helpful to control some of experimental conditions (i.e. temperature and humidity inside the cabin) keeping on the consistency of those parameters and conditions.

Selection of Operators

One operator is selected to wear the eye-tracking equipment. Operator's details are listed in the Tab. 3.1. The operator is mandated to perform his routine duties inside the selected vehicle cabin during conducting the windrowing operation.

Table. 3.1. Operator details

Name	Grebely Csaba
Age	22 years
Height	184 cm
Weight	78 kg
Experience	5 years

Selection of vehicle

CLAAS tractor (Model: ARES 567 ATZ) (Fig. 3.5) is selected to the purpose of accommodating the experimental trials.

Selection of experimental field

Experimental trials are conducted under the supervision of Szent István University management in a field called Babat-völgy to the north west of Gödöllő city (Fig. 3.9).

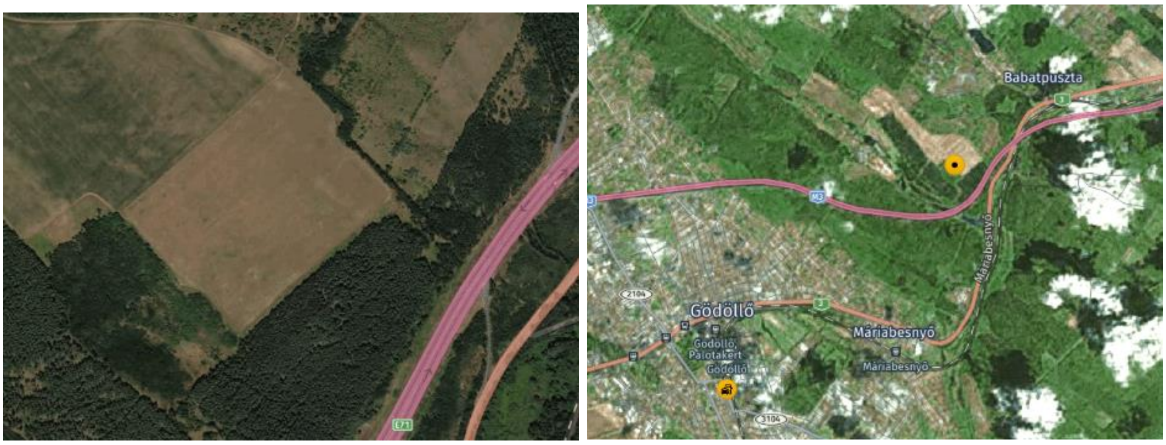


Fig. 3.9. Location of windrowing and baling experimental trials (Babat-völgy field)

Selection of areas of interest

To the purpose of this research, the selected area of interest is the attached tool CLAAS LINER 450T. Reference snapshot is taken for the item in the AOI form the video recorded by the Tobii Glasses 2 equipment (Fig. 3.10).

Fig. 3.10. Reference snapshot

3.3.2. Baling operation

Baling agricultural operation is selected to study and obtain the least used equipment inside a tractor cabin. After hay cutting in the agricultural field, windrowing operations are conducted to sort hay into lines in the field. Thereafter; the baling operation is conducted by specific tools attached to tractors generating hay bales in different shapes. To the purpose of this research, the used attached tool to the John Deere 6600 tractor is CLAAS ROLLANT 62S (Fig. 3.11).

Fig. 3.11. CLAAS ROLLANT 62S used for baling

Selection of operators

One operator is selected to wear the eye-tracking equipment. Operator’s details are listed in Tab. 3.2. The operator is mandated to perform his routine duties inside the selected vehicle cabin during conducting the baling operation.

Table. 3.2. Operator details

Name	Rácz Zoltán
Age	47 years
Height	178cm
Weight	67kg
Experience	30 years

Selection of vehicle

John Deere tractor (Model: 6600) is selected to the purpose of accommodating the experimental trials (Fig. 3.12).

Fig. 3.12. John Deere tractor (Model: 6600)

Selection of experimental field

Experimental trials are conducted under the supervision of Szent István University management in a field called Babat-völgy to the north west of Gödöllő city (Fig. 3.9).

Selection of areas of interest

To the purpose of this research, several areas of interest are selected to measure the operator's focusing to each AOI during the experimental execution time as listed in (Tab. 3.3). Reference snapshots are taken for the items in the areas of interest form the video recorded by the Tobii Glasses 2 equipment.

Table. 3.3. AOI's with reference snapshots

AOI Num.	**AOI**	**Reference snapshot**	**Item of interest**
1	Front dashboard		

2	Side panel		
3	Left mirror		
4	Right mirror		
5	Attached tool		

Selection of time of interest

To the purpose of this research, automatic real-world mapping tool is used along the time of interest (about 1478 seconds) to measure the operator's gaze on the selected items of interest in the reference snapshots.

3.3.3. Cultivating operation

The experimental trials are conducted for cultivating the sunflowers field using the vehicle (CASE 7210) with attached cultivating tool (Fig. 3.13).

Fig. 3.13. CASE 7210 with attached cultivating tool

CASE tractor (Model: CASE 7210) is selected to the purpose of accommodating the experimental trials in the cultivating operation.

Selection of areas of interest and time of interest:

Four different AOIs (Tab. 3.3) are selected to be studied, along two working days recording 39 samples each for 600 seconds (in total 23400 seconds).

Table. 3.3. Selected AOIs to be studied in the cultivating operation

AOI name	AOI reference image
Cultivating tool	
Dashboard	

Side panel	
Front panel	

Selection of experimental field

Experimental trials are conducted under the supervision of Szent István University management in a field beside Gödöllői airport to the south west of Gödöllő city (Fig. 3.14).

Fig. 3.14. Experiment field beside Gödöllői airport to the south west of Gödöllő city

3.3.4. Harvesting operation

The experimental trials are conducted for harvesting the sunflowers field using the vehicle (CLAAS Dominator 202) with front mounted harvesting tool (Fig. 3.15), in a field beside Gödöllői airport to the south west of Gödöllő city (Fig. 3.14).

Fig. 3.15. CLAAS Dominator 202 with front mounted harvesting tool

CLAAS Dominator 202 is selected to the purpose of accommodating the experimental trials in the harvesting operation.

Selection of areas of interest and time of interest:

The front-mounted tool (AOI) is selected to be studied (Fig. 3.16), along 13 recording samples each for 600 seconds (in total 7800 seconds).

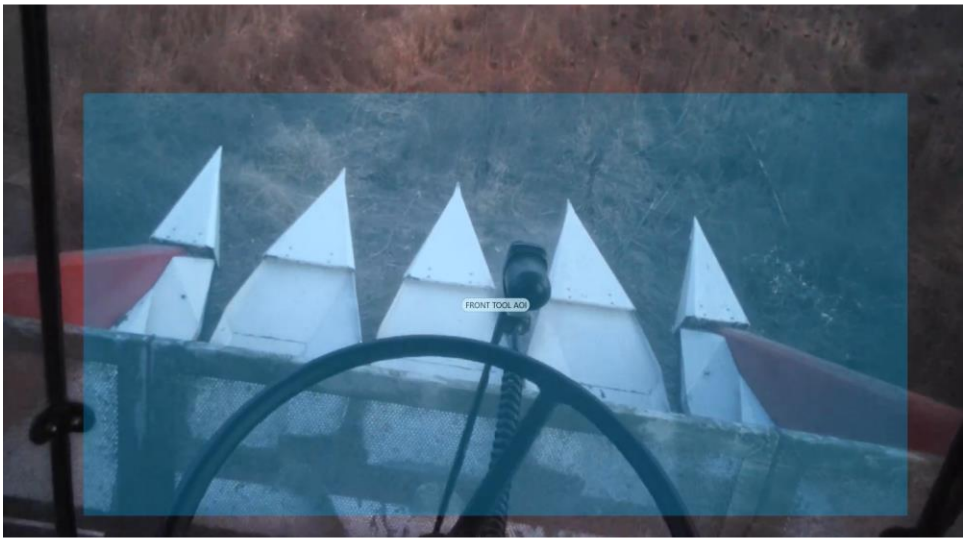


Fig. 3.16. The front-mounted tool (AOI)

3.4. Experimental procedure

3.4.1. The process map for the experimental procedure

To the purpose of this research, the followed methodology is summarized in process map showed in (Fig. 3.17). However; the scope is subjected to be extended upon the accomplishment of all research phases to test innovative design enhancements and engineering solutions and compare different models of change on operator's focusing scheme along working hours in different agricultural operations.

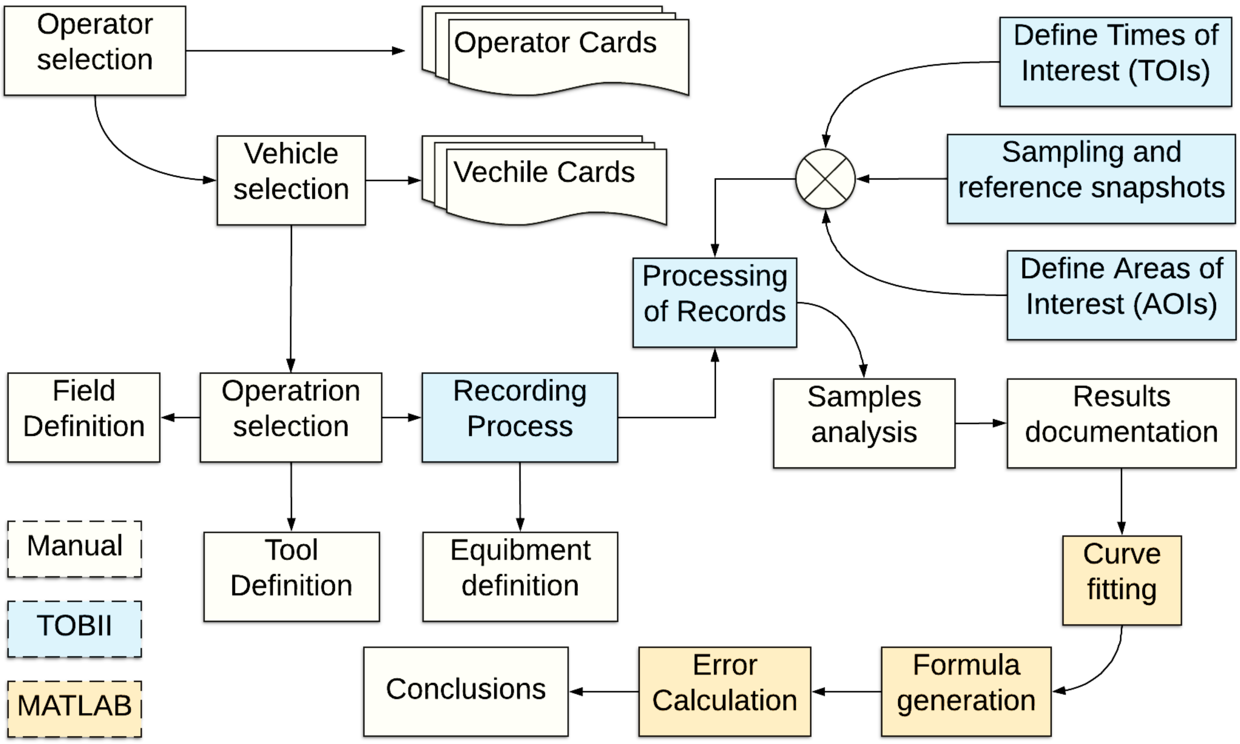


Fig. 3.17. Methodology process map

The operator is mandated to wear Tobii glasses and to go through the calibration process whenever a new recording is started. The glasses are connected wirelessly to the windows tablet which is running the Tobii controller software to register the recording information, monitor the real-time view of the operator, conduct the calibration process and to stop, pause and start the recording process.

Thereafter, the collected video recordings are transferred to the PC which is running the Tobii Pro Lab software to be analyzed using the real-time mapping and available filtering packages to obtain the accumulated times.

3.4.2. The preparation of the experimental results

After accomplishing the analysis process, the resulted data was exported by Tobii Pro Lab analyzer software to MS Excel sheet. The samples were normalized in accordance to the mentioned normalization formula.

In the next chapter, tables are prepared to present sample of exported results the agricultural operations, where:

- The sample reference in the original video (column 1); which represents the reference of a certain sample inside the used analyzer software (Tobii Pro Lab).
- The sample serial number (X) (column 2); which will represent the X-Axis on the resulted curve.
- The tool snap times in (X) sample (column 3); which will represent the accumulated time of operator's gaze inside the AOI on the Y-Axis on the resulted curve.
- The normalization factor (N) for the sample (X) (column 4).
- The Normalized tool snap times (X*N) (column 5).
- The generated heat map for the sample (X) (column 6); which is a graphical representation for the operator's gaze distribution and accumulated time over the reference image along the sample recording time.

3.4.3. Sampling

To measure the operator's focusing on the AOI during the experimental samples of execution times recording samples are used. Each recording sample (X) represents 600 seconds of the real-time recording of the operator's gaze during the all tested agricultural operations.

Due to the differences between the planned and actual recoding time, each sample is normalized to represent the 600 seconds of recording with a factor (N). the shortest recorded sample was less than the planned recording time by 17%. However, collected snap times on the attached tool is multiplied by the Normalization factor (N) according to the formula:

$$X_{\text{Normalized}} = (N) * (X_{\text{Actual}}).$$

To the purpose of this research, automatic real-world mapping tool is used along the time of interest (about 6600 seconds) to measure the operator's gaze on the selected area of interest in the reference snapshot.

Turing over at the field edges requires a special attention by the operator to the attached tools and the used panels and monitors inside the cabin, mainly for steering purposes and to de-attach the tool from the working field avoiding any unexpected or unnecessary to be treated obstacles.

Such special process if happened more than once during the sample (600 seconds) the resulted values will be obviously distinguished from previous and following samples results in which there were no turnovers, or it happened once during the sample.

The samples were not manipulated to uniformly split the turnover cases over samples due to the randomization found in each sample length, however; the results were treated at later stages by the curve fitting techniques developing the model of operator's focusing scheme change along working hours for each agricultural operation.

The samples which were excluded from the records were limited to the following cases:

- Familiarization process

- Due being out of the vehicle for a limited time to conduct an unrelated to the experiments results tasks such as:
    - Being out of the vehicle to conduct a quick maintenance operation.
    - Changing the battery of the recording unit.
    - Conducting the recalibration process after starting new recording session.
    - Stopping for eat or drink.
- Samples with less than 6 minutes of recording.

3.5. MATLAB curve fitting toolbox

Curve Fitting Toolbox™ provides an app and functions for fitting curves and surfaces to data. The toolbox lets you perform exploratory data analysis, pre-process, and post-process data, compare candidate models, and remove outliers. The application can be used to conduct regression analysis using the library of linear and nonlinear models provided or specify custom equations. The library provides optimized solver parameters and starting conditions to improve the quality of your fits. The toolbox also supports nonparametric modelling techniques, such as splines, interpolation, and smoothing.

The Curve Fitting Toolbox (Fig. 3.18) is used to give the Models of the change on operator's focusing scheme along working hours for the samples collected from agricultural.

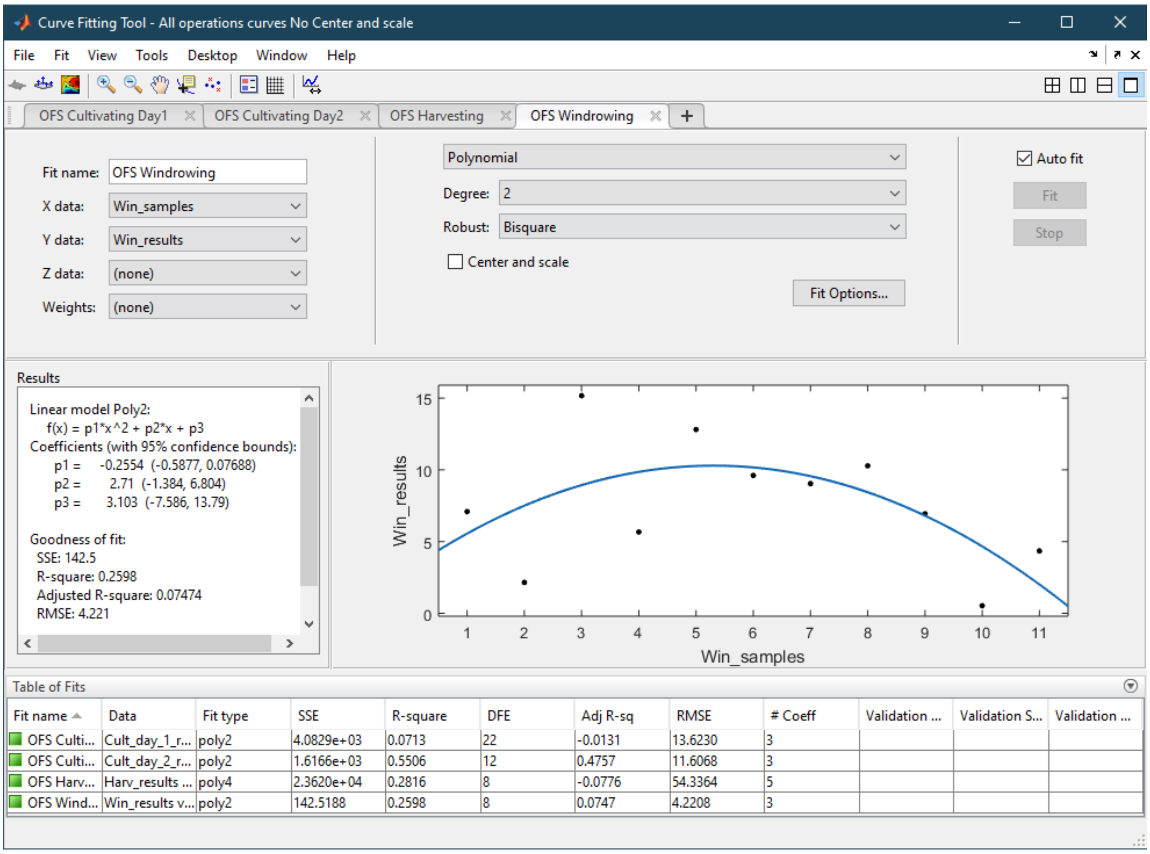


Fig. 3.18. Curve fitting toolbox - MATLAB

The planned experimental steps were executed successfully, producing different models for the tested agricultural operations, and the methodology was validated to be used to determine percentage of distribution of operator focusing scheme inside off-road vehicle cabins for the design evaluation purposes. Which is the start of obtaining the results conducting on-site experiments to produce the models of different agricultural operations and to prove the methodology success to provide an accurate and deterministic data for the statistical readings as a necessary input for designers to upgrade the current work places which could be a cockpit or an off-road vehicle cabin in addition to designing the generations to come of highly automated workplaces considering the human factor design bases at early stages.

4.1. Methodology testing and validation

In order to ensure the completeness and functionality of the proposed mechanism to obtain the change of operator's focusing scheme change along working hours, the indoor testing process is conducted inside SZIE laboratory to obtain readings of operator's focusing scheme on two different areas of interest.

In prior to start recording, the calibration process is done successfully and confirmed automatically by the Tobii controller software and the special calibration card.

Two AOIs are selected inside the tractor cabin (Fig. 4.1) as follows:

- AOI1: the notification panel in the tractor dashboard and the Air conditioning rotary switch.
- AOI2: the side control panel in the tractor right side.

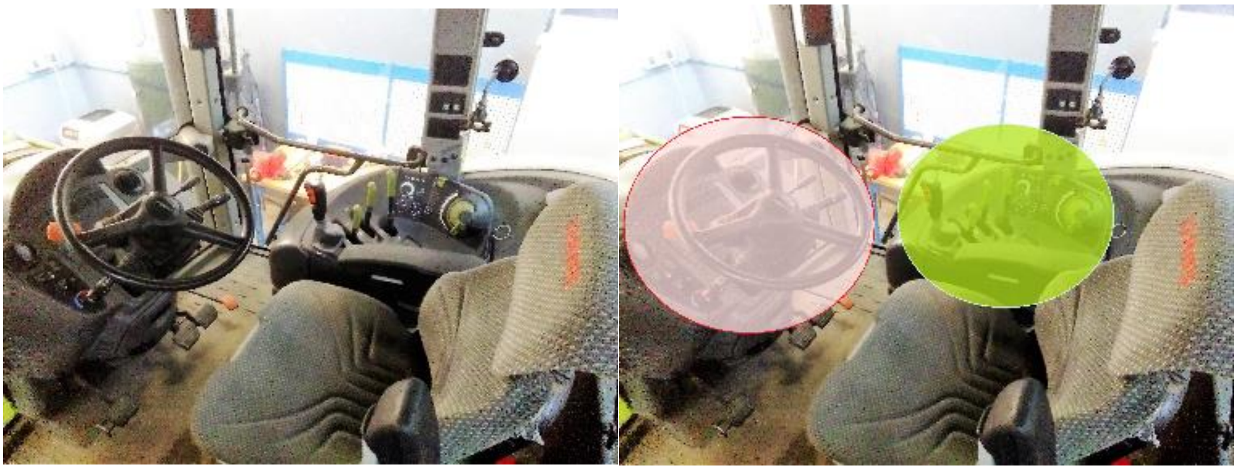


Fig. 4.1. Tractor cabin and the selected AOIs locations

The recorded video is processed using the Tobii Lab Pro software. The full recording time was about 520.53 seconds.

The AOI1 (Fig. 4.2) is represented into two components in the front dashboard. The air conditioning rotary switch and the notification panel. From the variety of available data which the Tobii Lab Pro software is capable to provide, main collected data from AOI1 was limited to the accumulated gaze time spent on the selected components "in seconds" and the counts representing the number of times in which each component is scanned by the operator (Tab. 4.1) and the heat map is generated (Fig. 4.3).

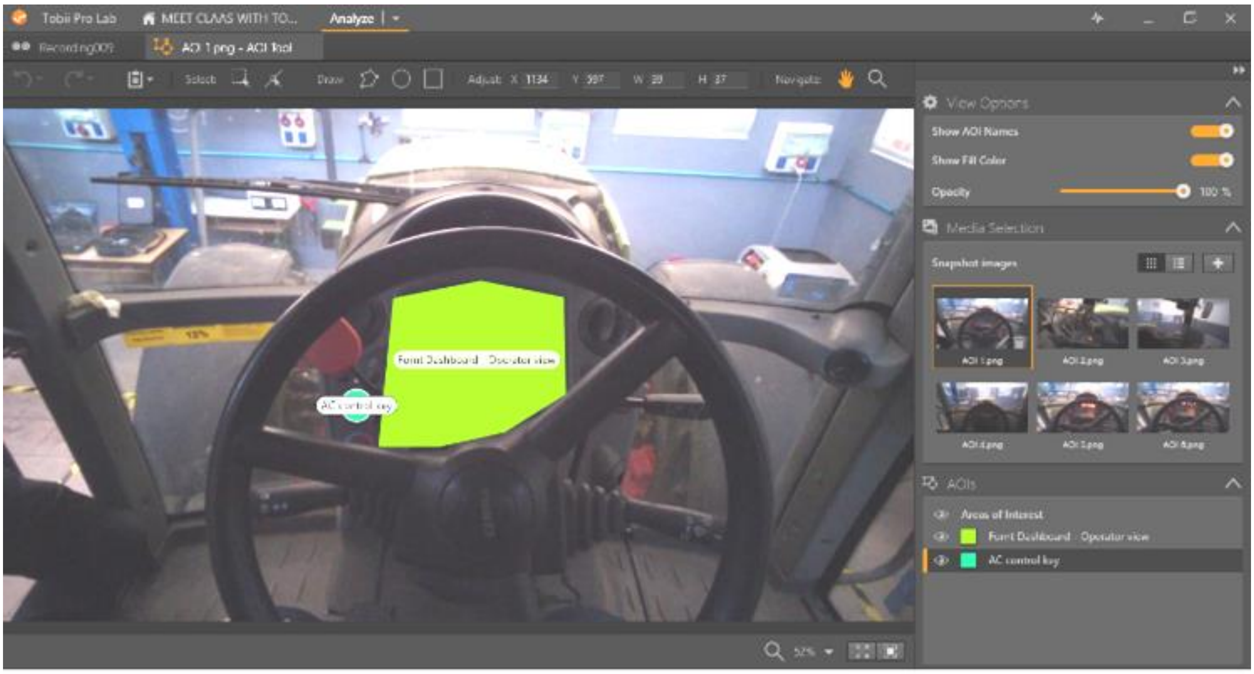


Fig. 4.2. AOI1 the notification panel in the tractor dashboard and the AC rotary switch

Table. 4.1. AOI (1) collected data

Total Visit Duration	AC Rotary switch	Front Dashboard	Sum	Total Time of Interest Duration	Total Recording Duration
Time (seconds)	0.67	100.11	100.78	290.13	520.53
Counts	4	239	243		

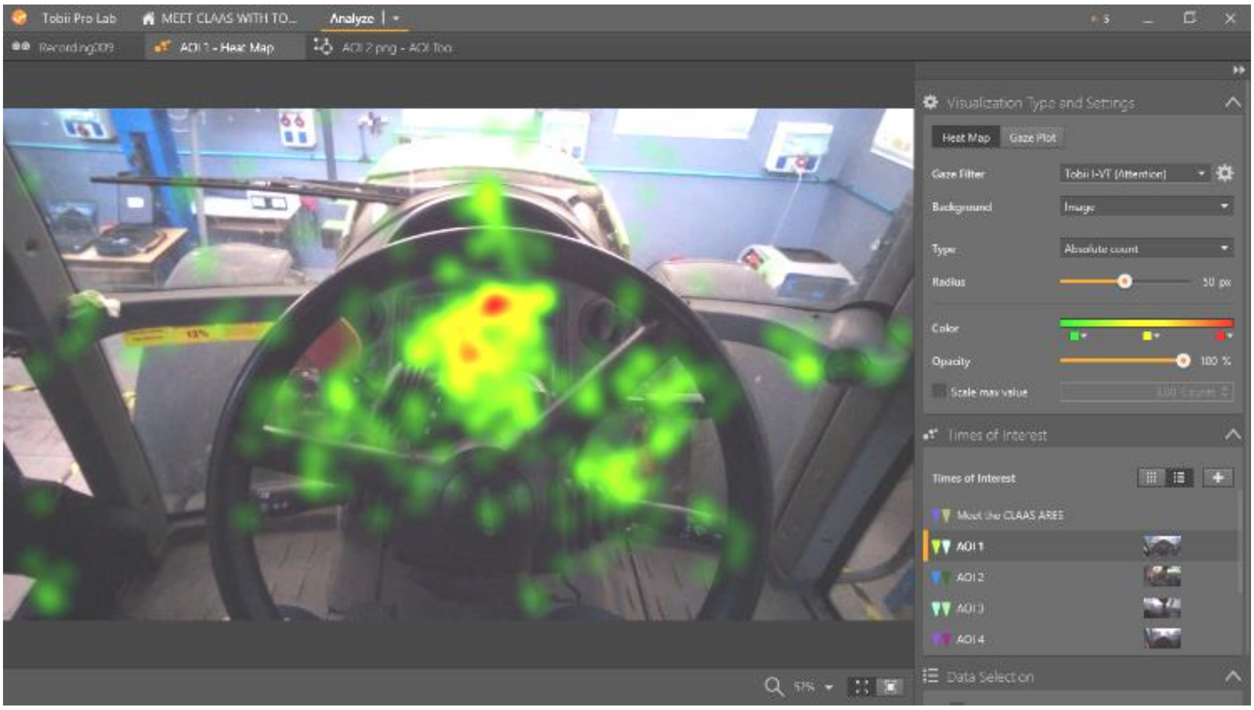


Fig. 4.3. AOI (1) generated heat map

The AOI2 (Fig. 4.4) is represented into side control panel components in the tractor cabin. From the variety of available data which the Tobii Lab Pro software is capable to provide, main collected data from AOI2 was limited to the accumulated gaze time spent on the selected components "in seconds" and the counts representing the number of times in which side control panel components are scanned by the operator (Tab. 4.2) and the heat map is generated (Fig. 4.5).

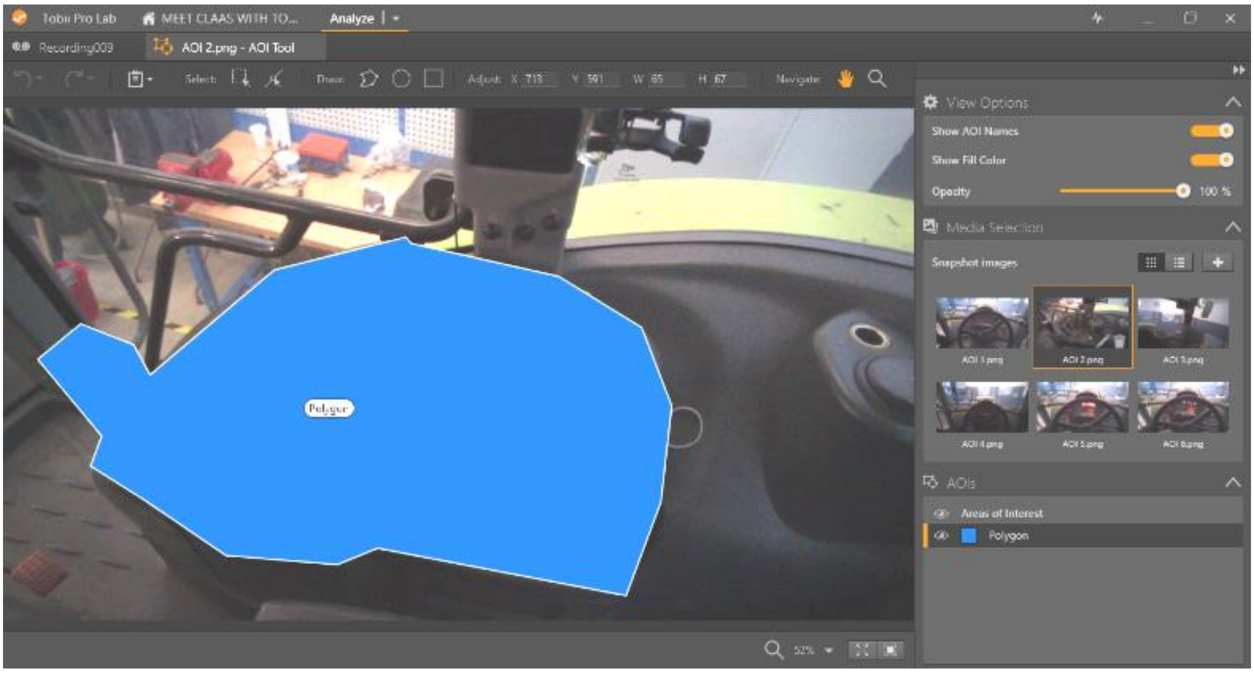


Fig. 4.4. AOI (2) the side control panel in the tractor right side

Table. 4.2. AOI (2) collected data

Total Visit Duration	Side control panel	Sum	Total Time of Interest Duration	Total Recording Duration
Time (seconds)	33.88	33.88	54.94	520.53
Counts	77	77		

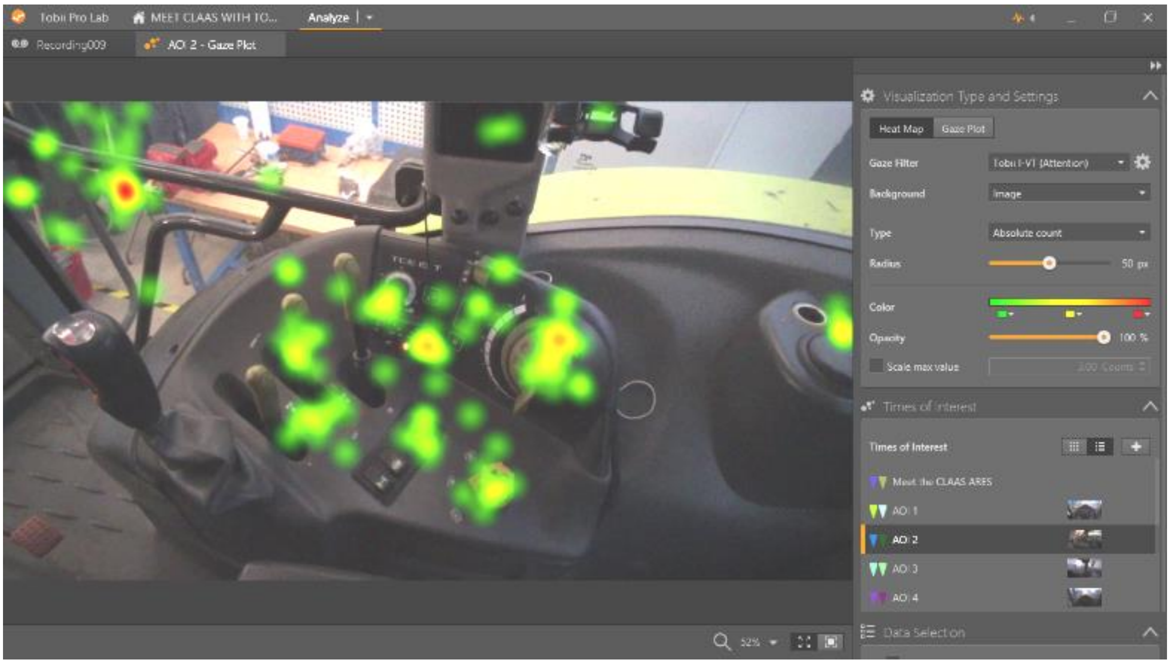


Fig. 4.5. AOI (2) generated heat map

4.2. Windrowing operation results

The windrowing operation trials were conducted along two normal summer days in June 2017 by the operator (Grebely Csaba) using the CLAAS tractor (Model: ARES 567 ATZ) in a field called Babat-völgy to the north west of Gödöllő city.

By selecting the attached rear tool CLAAS LINER 450T (Fig. 4.6) as an AOI, the experimental trials were conducted successfully. The results are obtained and analysed accordingly.

Fig. 4.6. The selected AOI for windrowing operation

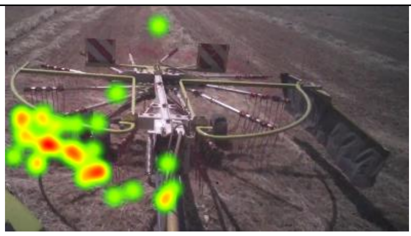
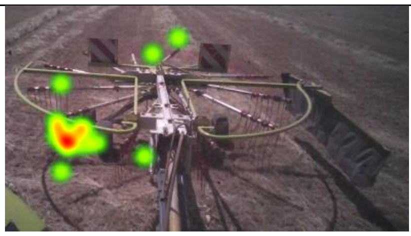
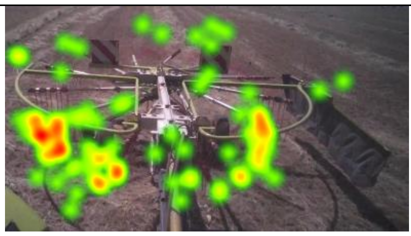
4.2.1 Windrowing operation recording results

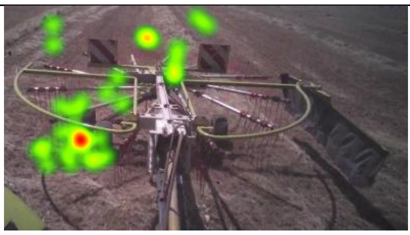
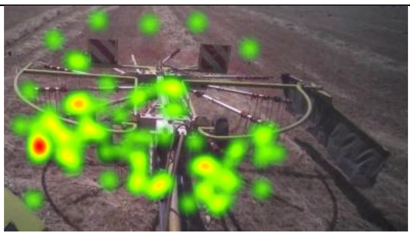
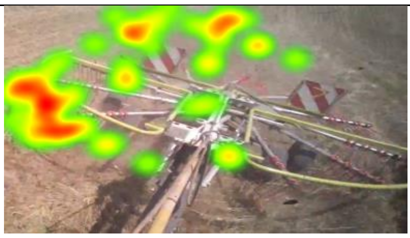
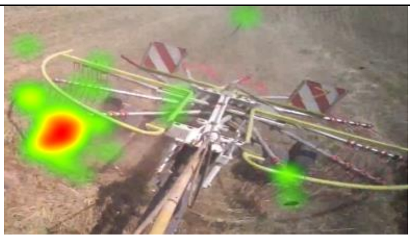
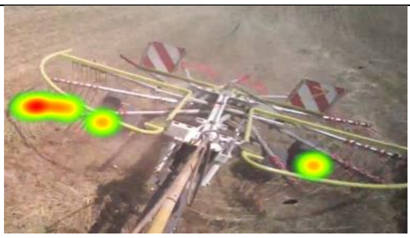
After accomplishing the analysis process, the resulted data was exported by Tobii Pro Lab analyser software to MS Excel sheet which is presented as raw data in Appendix A3 (Tab. A3.1). The samples were collected and normalized in accordance to the normalization formula.

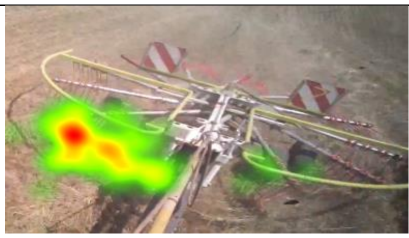
Tab. 4.3 presents sample of exported results for the windrowing operation and cultivating operation, where:

- The sample reference in the original video (column 1); which represents the reference of a certain sample inside the used analyser software (Tobii Pro Lab).
- The sample serial number (X) (column 2); which will represent the X-Axis on the resulted curve.
- The tool snap times in (X) sample (column 3); which will represent the accumulated time of operator's gaze inside the AOI on the Y-Axis on the resulted curve.
- The normalization factor (N) for the sample (X) (column 4).
- The Normalized tool snap times (X*N) (column 5).
- The generated heat map for the sample (X) (column 6); which is a graphical representation for the operator's gaze distribution and accumulated time over the reference image along the sample recording time.

Table. 4.3. Experiment results of windrowing operation

Sample Reference	X value	Tool Snap time (Sec)	N Factor	Time (Normalized) (Sec)	Generated Heat map
8	5	7.09	1.00	7.09	
9	6	2.15	1.00	2.15	
10	7	15.17	1.00	15.17	

11	8	5.67	1.00	5.67	
12	9	15.38	0.83	12.82	
13	10	9.37	1.03	9.61	
14	11	9.04	1.00	9.04	
15	12	12	0.86	10.29	
16	13	6.94	1.00	6.94	
17	14	0.53	1.00	0.53	

18	15	4.89	0.89	4.35	

Putting the resulted data of accumulated time of each sample on the y-axis and the and the samples sequence on the x-axis, after the normalization of results based on the actual recording time to represent 600 seconds of recording for each sample, the results are shown in (Fig. 4.7).

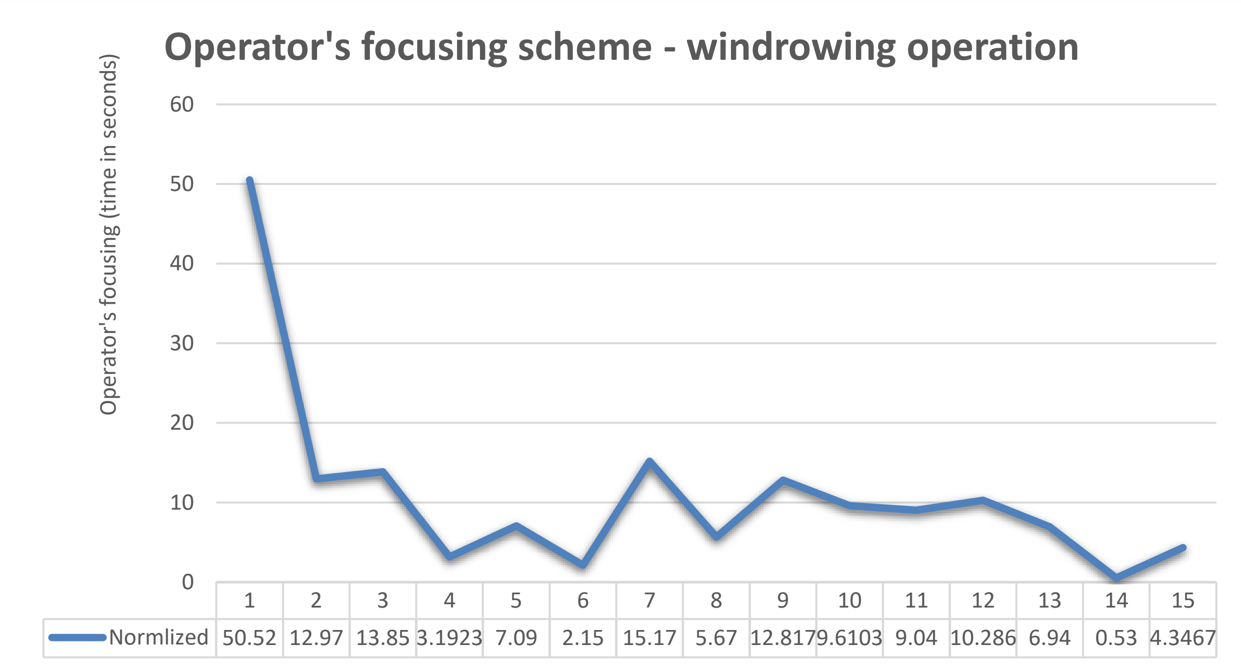


Fig. 4.7. Accumulated time of operator’s focusing scheme for each sample in the windrowing operation

4.2.2 Excluded samples

Because it was the first real-time recording experience for the selected operator, the first four samples are excluded from the modelling scope to avoid any misleading inputs due to the familiarization process of the operator with the system configuration. Which required joining the operator in the tractor cabin to explain the mechanism and the target behaviour as shown in (Fig. 4.8).

Fig. 4.8. Familiarization process of the operator with the system configuration

4.2.3 Curve fitting results

The curve fitting operation is conducted using the MATLAB Curve Fitting Toolbox™, the resulted curves for the windrowing operation (Fig. 4.9).

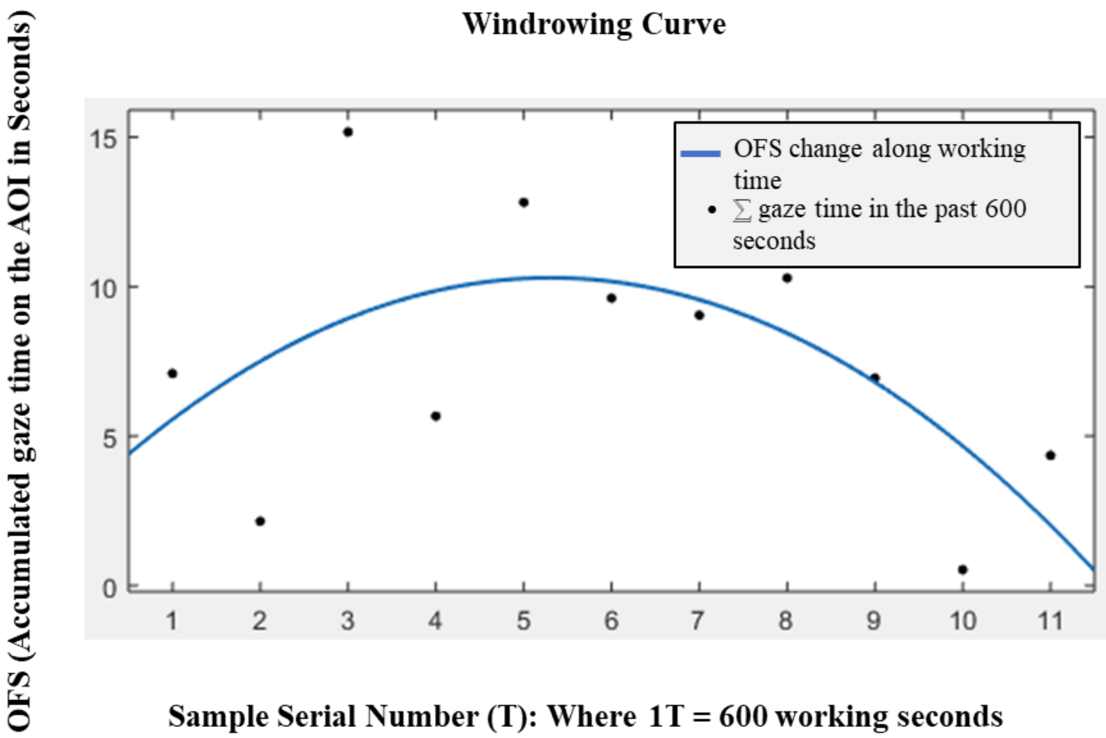


Fig. 4.9. Results of curve fitting for windrowing agricultural operation

4.2.4 Modelling results

The resulted data was processed selecting the Linear model (Poly 2) which generates a polynomial equation with the second degree and using Bi-square robust method.

The results showed the operator's gaze on selected area of interest. The used equipment and supporting software packages easily defined the time in which the operator paid his attention to the attached windrowing tool during working time in the windrowing operation developing the model describing the change on the OFS along working time Xwindr (T) where T is the sample number and represents the past 600 working seconds:

$$X\text{windr}(T) = 3.103 + 2.71T - 0.2554T^2$$

4.3. Cultivating operation results

The cultivating operation trials were conducted along two days in October 2017 by the operator (Grebely Csaba) using the CASE tractor (Model: 7210) in a field beside Gödöllői airport to the south west of Gödöllő city.

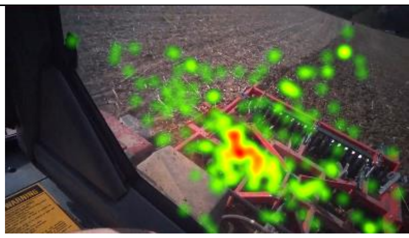
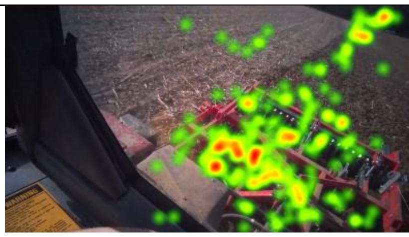
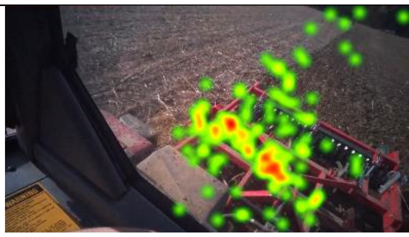
By selecting the attached rear tool (Fig. 4.10) as an area of interest, the experimental trials were conducted successfully. The results are obtained and analysed accordingly.

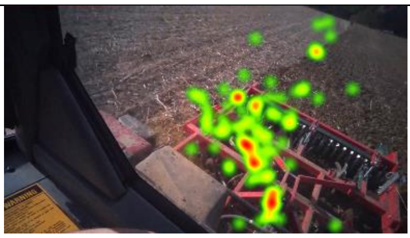
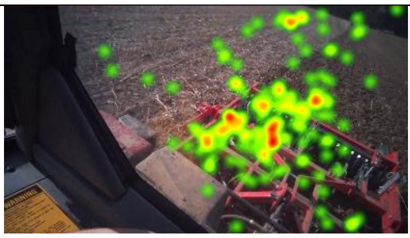
Fig. 4.10. The attached rear tool for cultivating operation

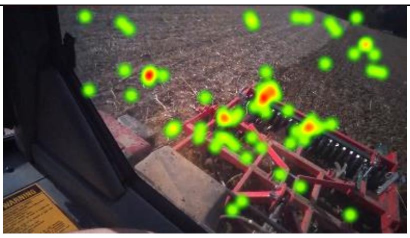
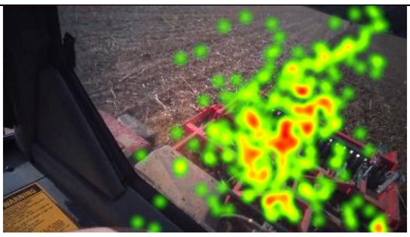
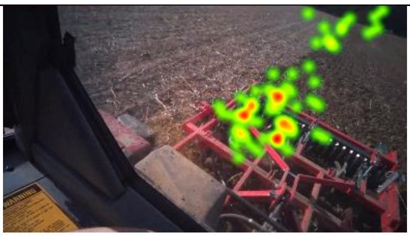
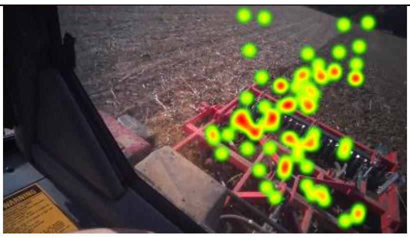
4.3.1 Cultivating operation recording results

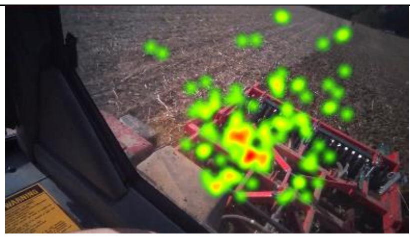
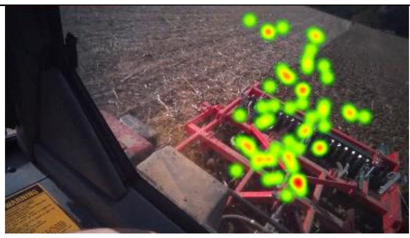
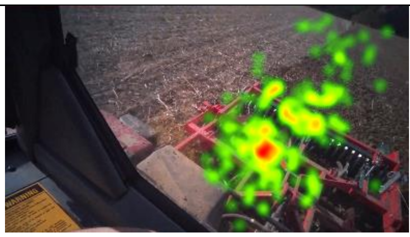
After accomplishing the analysis process, the resulted data was exported by Tobii Pro Lab analyser software to MS Excel sheet which is presented as raw data in Appendix A3 (Tab A3.2). The samples were collected and normalized in accordance to the mentioned normalization formula and the exported results (Tab. 4.4) showed the following:

Table 4.4. Experiment results of cultivating operation

Sample Reference	X value	Tool Snap time (Sec)	N Factor	Time (Normalized) (Sec)	Generated Heat map
Day 1					
15	1	21.74	1.00	21.74	
16	2	2.60	1.00	2.60	
17	3	7.92	1.00	7.92	
18	4	48.72	1.00	48.72	
19	5	41.60	1.00	41.60	
20	6	28.49	1.00	28.49	

21	7	2.15	1.00	2.15	
22	8	0.00	1.00	0.00	
23	9	0.00	1.00	0.00	
Sample Reference	X value	Tool Snap time (Sec)	N Factor	Time (Normalized) (Sec)	Generated Heat map
Day 2					
24	10	24.31	1.00	24.31	
25	11	7.45	1.00	7.45	
26	12	32.29	1.00	32.29	

27	13	0.00	1.00	0.00	
28	14	10.17	1.00	10.17	
29	15	3.66	1.00	3.66	
30	16	11.33	1.00	21.74	
31	17	2.53	1.00	2.60	
32	18	13.35	1.00	7.92	
33	19	3.66	1.00	48.72	

34	20	10.23	1.00	41.60	
35	21	0.00	1.00	28.49	
36	22	7.19	1.00	2.15	
37	23	24.27	1.00	0.00	
38	24	7.43	1.00	0.00	
39	25	7.08	1.00	24.31	

Putting the resulted data of accumulated time of each sample on the y-axis and the samples sequence on the x-axis, after the normalization of results based on the actual recording time to represent 600 seconds of recording for each sample, the results are shown in (Fig. 4.11) for the first day and (Fig. 4.12) for the second day.

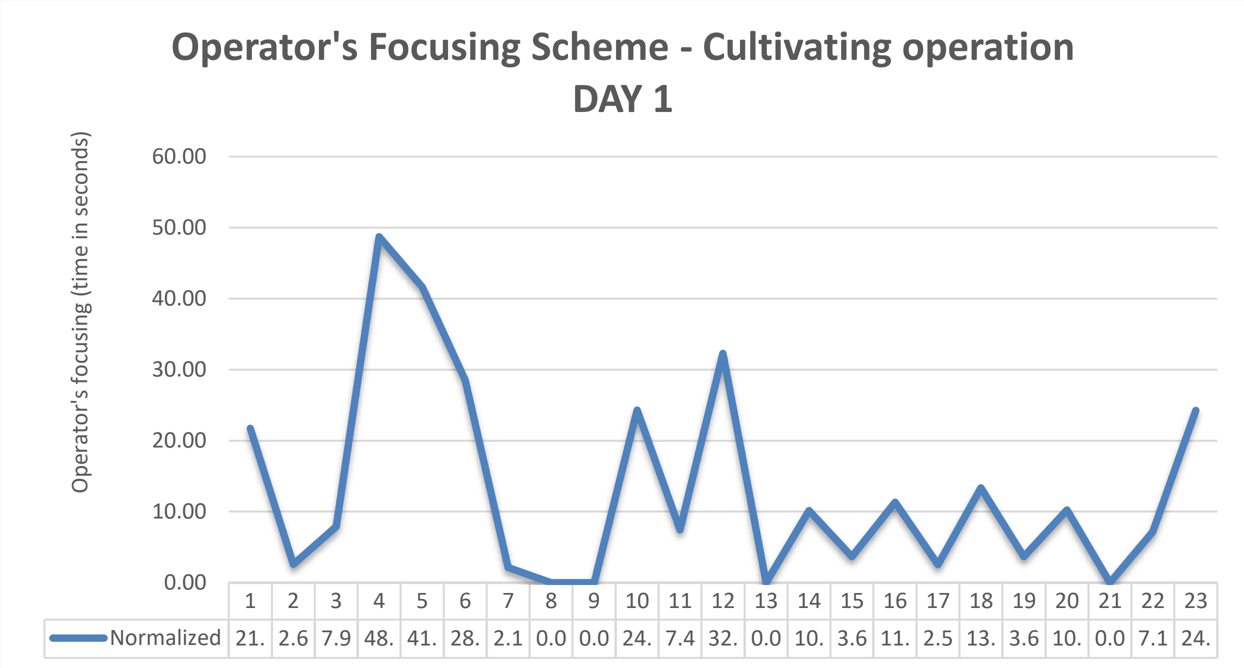


Fig. 4.11. Accumulated time of operator's focusing scheme for each sample in cultivating agricultural operation – Day1

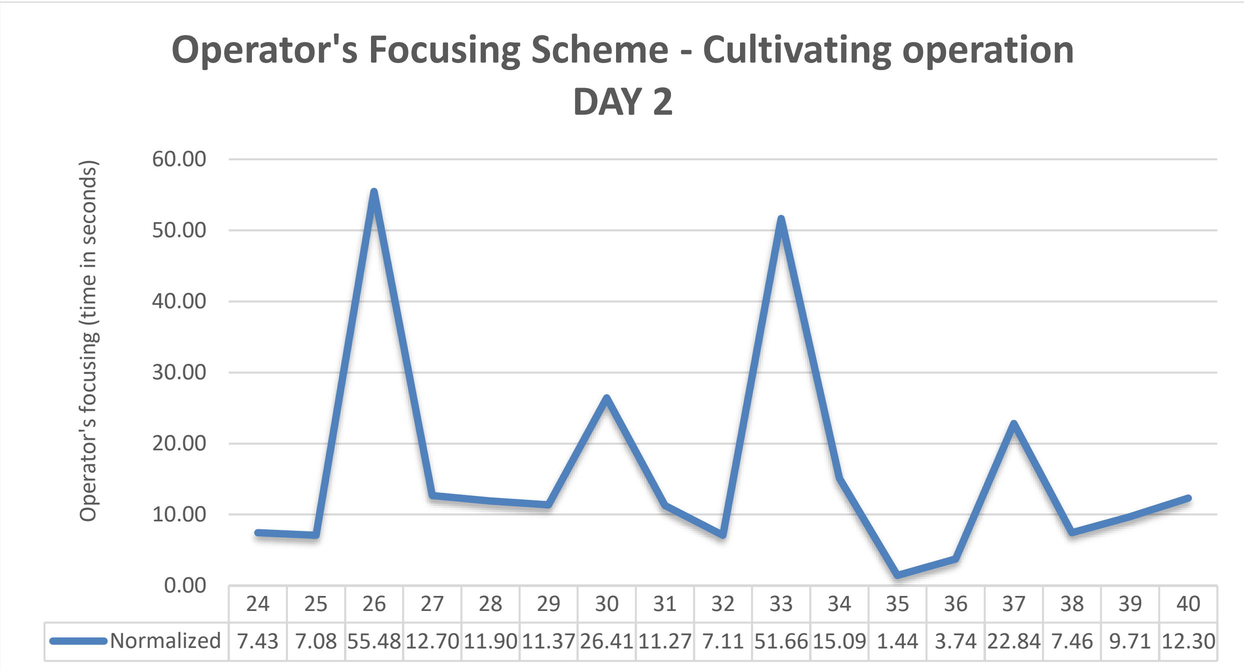


Fig. 4.12. Accumulated time of operator's focusing scheme for each sample in cultivating agricultural operation – Day2

4.3.2 Curve fitting results

The curve fitting operation is conducted using the MATLAB Curve Fitting Toolbox™, the resulted curves for the cultivating operation (Fig. 4.13) for the first day and (Fig. 4.14) for the second day.

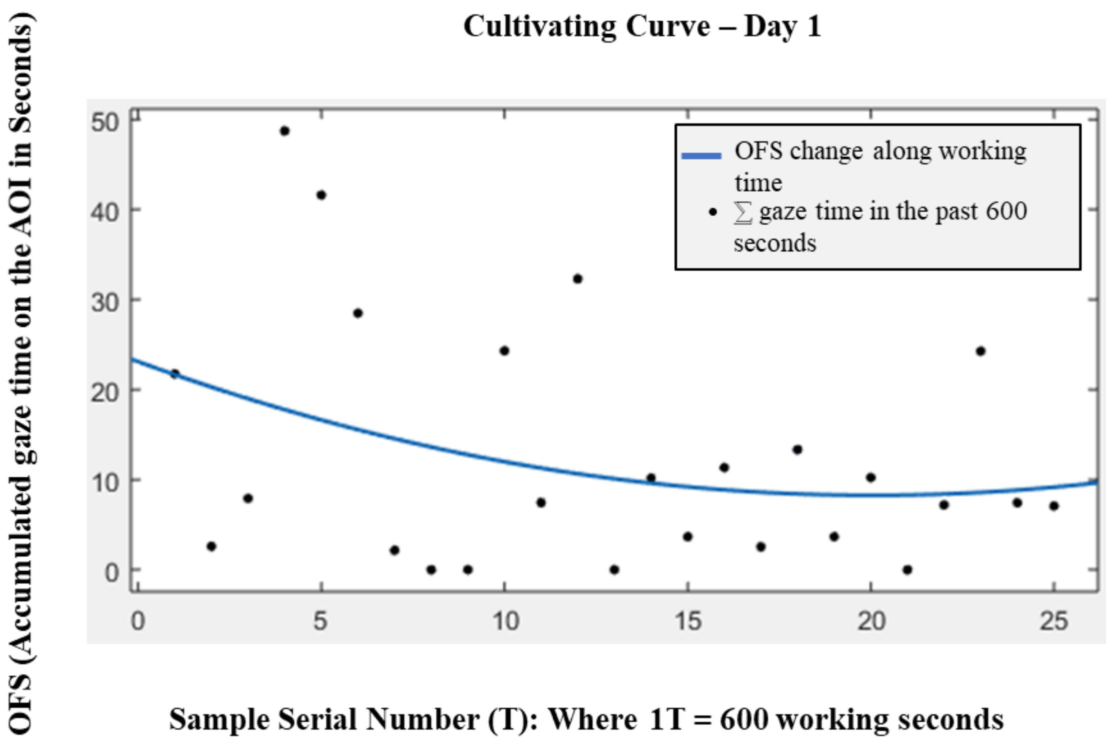


Fig. 4.13. Results of curve fitting for cultivating agricultural operation – day 1

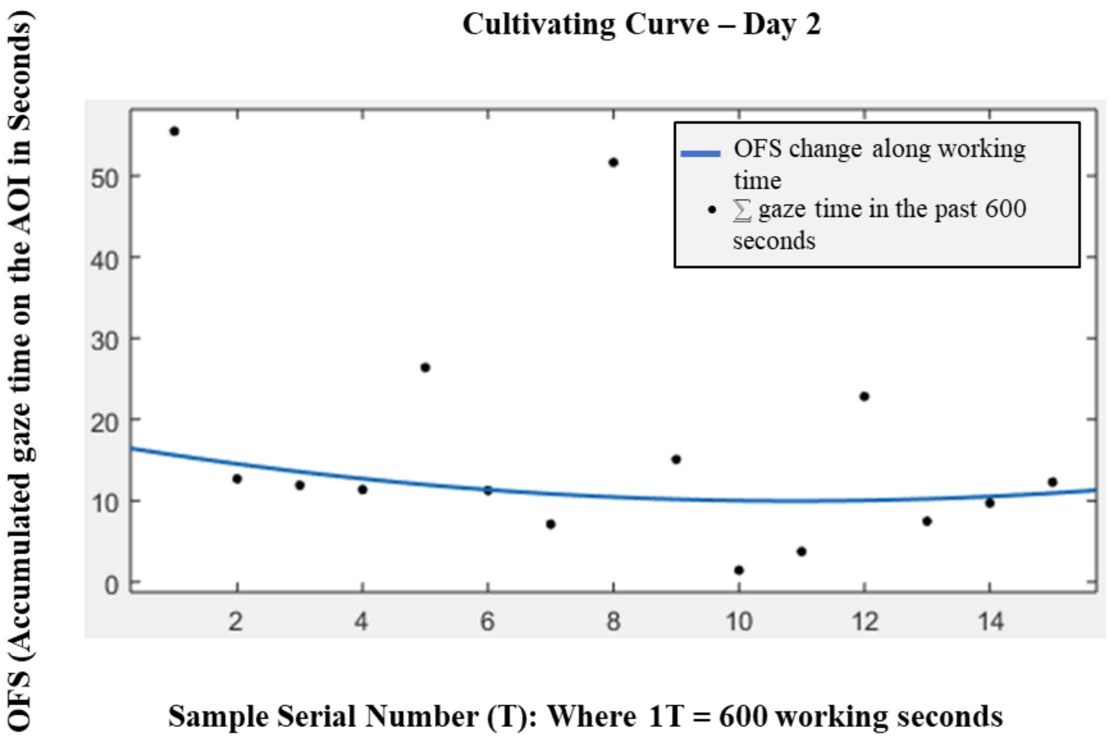


Fig. 4.14. Results of curve fitting for cultivating agricultural operation – day 2

4.3.3 Modelling results

The resulted data was processed selecting the Linear model (Poly 2) which generates a polynomial equation with the second degree and using Bi-square robust method.

The results showed the operator's gaze on selected area of interest. The used equipment and supporting software packages easily defined the time in which the operator paid his attention to the attached windrowing tool during working time in the cultivating operation developing the model describing the change on the OFS along working time Xcult (T) where T is the sample number and represents the past 600 working seconds:

Day 1 resulted model: $Xcult(T) = 23.10 - 1.480T + 0.03691T^2$

Day 2 resulted model: $Xcult(T) = 16.81 - 1.256T + 0.05763T^2$

4.4. Harvesting operation results

The harvesting operation experimental trials were conducted along one day in October 2017 by the operator (Grebely Csaba) using the vehicle (CLAAS Dominator 202) in a field beside Gödöllői airport to the south west of Gödöllő city.

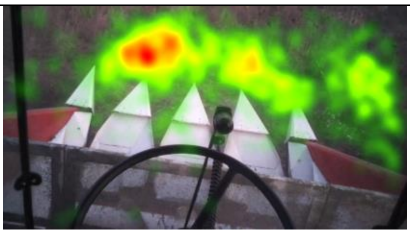
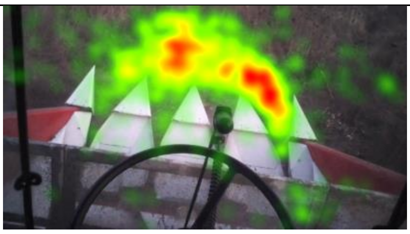
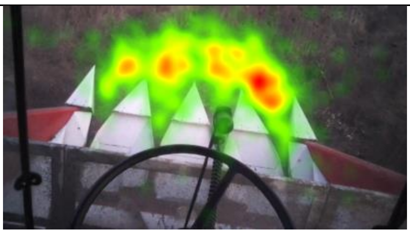
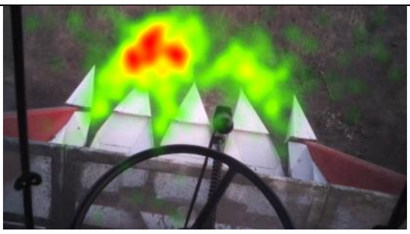
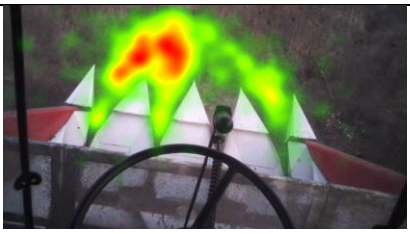
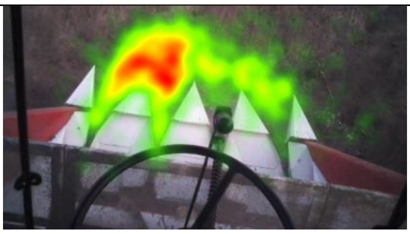
By selecting the attached front harvesting tool (Fig. 4.15) as an area of interest, the experimental trials were conducted successfully. The results are obtained and analysed accordingly.

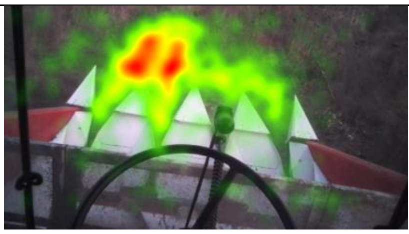
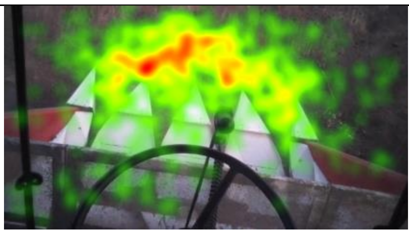
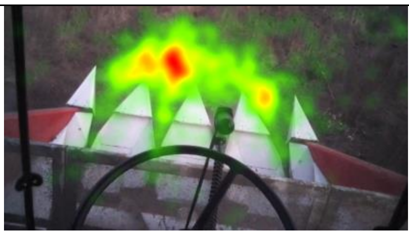
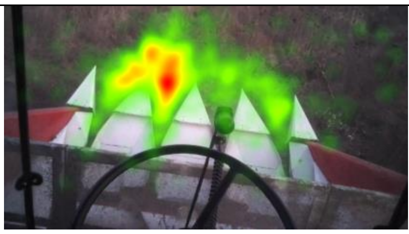
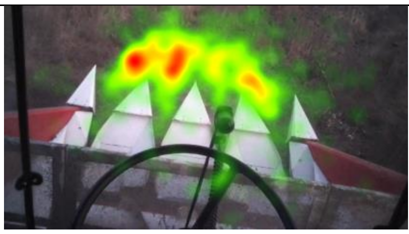
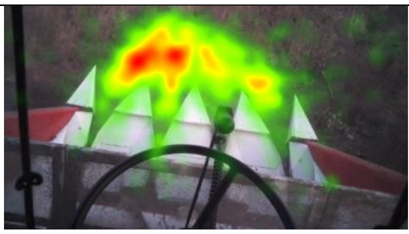
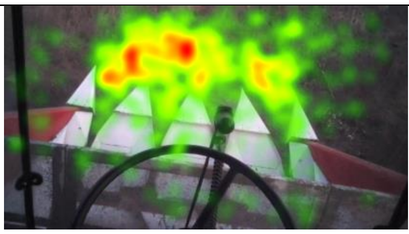
Fig. 4.15. The attached front tool for harvesting operation

4.4.1 Harvesting operation recording results

After accomplishing the analysis process, the resulted data was exported by Tobii Pro Lab analyser software to MS Excel sheet which is presented as raw data in Appendix A3 (Tab. A3.3). The samples were normalized in accordance to the mentioned normalization formula and the exported results (Tab. 4.5) showed the following:

Table 4.5. Experiment results of harvesting operation

Sample Reference	X value	Tool Snap time (Sec)	N Factor	Time (Normalized) (Sec)	Generated Heat map
1	1	481	0.90	245.52	
2	2	413.5	1.00	274.79	
3	3	500.05	1.00	369.99	
4	4	409.89	1.00	282.74	
5	5	440.73	1.00	362.42	
6	6	503.6	1.00	342.11	

7	7	455.33	1.00	251.89	
8	8	384.22	1.00	203.28	
9	9	452.52	1.00	318.01	
10	10	499.41	1.00	289.25	
11	11	391.41	1.00	300.01	
12	12	481.3	1.00	343.33	
13	13	280	1.34	229.23	

Putting the resulted data of accumulated time of each sample on the y-axis and the and the samples sequence on the x-axis, after the normalization of results based on the actual recording time to represent 600 seconds of recording for each sample, the results are shown in (Fig. 4.16).

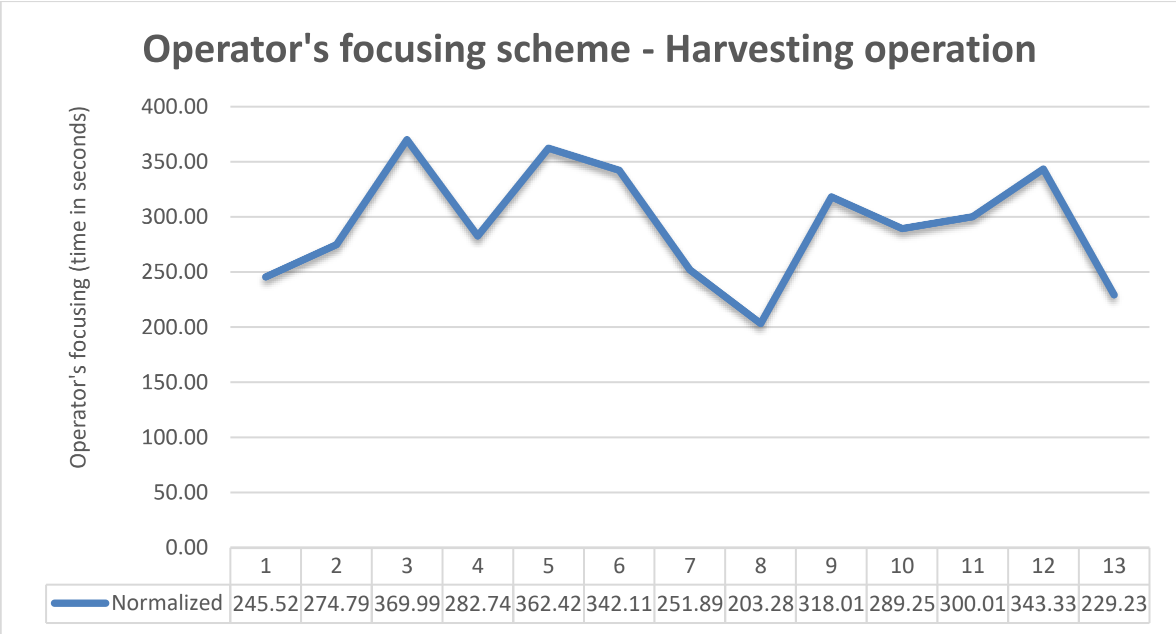


Fig. 4.16. Accumulated time of operator’s focusing scheme for each sample in harvesting agricultural operation

4.4.2 Curve fitting results

The curve fitting operation is conducted using the MATLAB Curve Fitting Toolbox™, the resulted curves for the harvesting operation (Fig. 4.17).

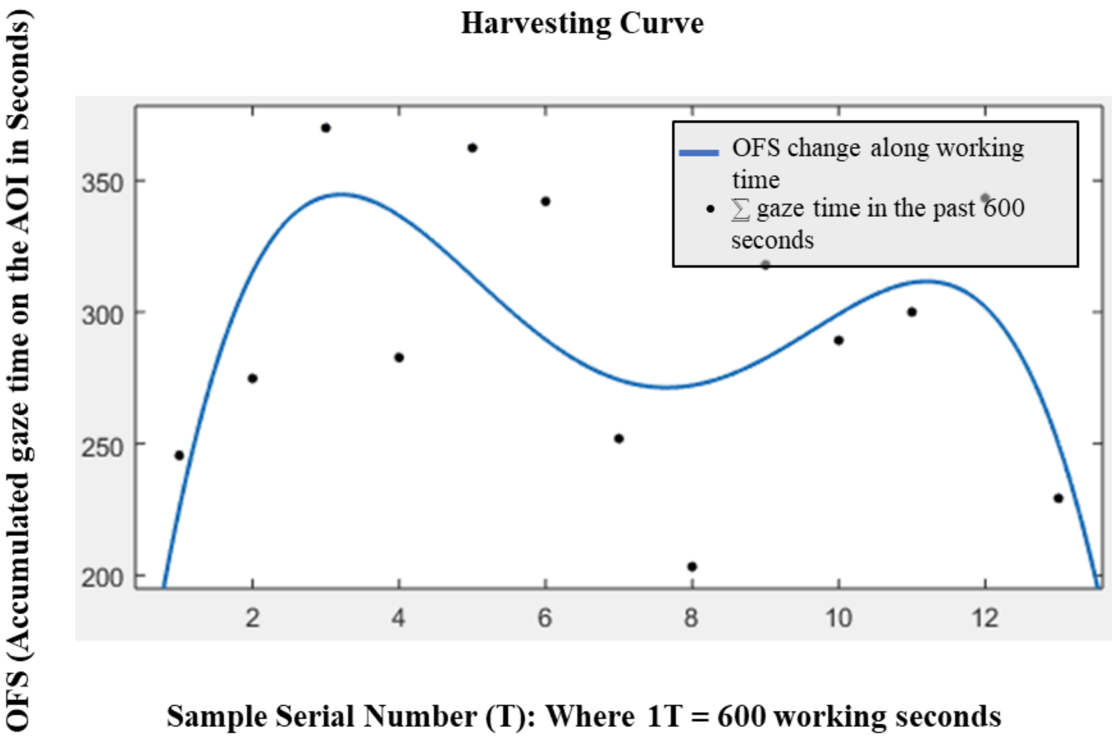


Fig. 4.17. Results of curve fitting for harvesting agricultural operation

4.4.3 Modelling results

The resulted data was processed selecting the Linear model (Poly 4) which generates a polynomial equation with the fourth degree and using Bi-square robust method.

The results showed the operator's gaze on selected area of interest. The used equipment and supporting software packages easily defined the time in which the operator paid his attention to the front mounted tool during working time in the harvesting operation developing the model describing the change on the OFS along working time Xharv (T) where T is the sample number and represents the past 600 working seconds:

$$Xharv(T) = 43.6 + 239.2T - 63.58T^2 + 6.397T^3 - 0.2175T^4$$

4.5. Developed models of the selected agricultural operations

The curve fitting operation is conducted using the MATLAB Curve Fitting Toolbox™, the resulted curves for the windrowing (Fig. 4.9), cultivating (day 1 (Fig. 4.13) and day 2 (Fig. 4.14)) and harvesting operations (Fig. 4.17).

The resulted models and the goodness of fit is shown in (Tab. 4.6).

Table 4.6. Resulted models and the goodness of fit

Windrowing operation model	Cultivating operation model (day 1)	Cultivating operation model (day 2)	Harvesting operation model
Linear model Poly2: f(x) = p1*x^2 + p2*x + p3 p1 = -0.2554 p2 = 2.71 p3 = 3.103 Goodness of fit: R-square: 0.2598 RMSE: 4.221	Linear model Poly2: f(x) = p1*x^2 + p2*x + p3 p1 = 0.03691 p2 = -1.48 p3 = 23.1 Goodness of fit: R-square: 0.0713 RMSE: 13.62	Linear model Poly2: f(x) = p1*x^2 + p2*x + p3 p1 = 0.05763 p2 = -1.256 p3 = 16.81 Goodness of fit: R-square: 0.5506 RMSE: 11.61	Linear model Poly4: f(x) = p1*x^4 + p2*x^3 + p3*x^2 + p4*x + p5 p1 = -0.2175 p2 = 6.397 p3 = -63.58 p4 = 239.2 p5 = 43.6 Goodness of fit: R-square: 0.2816 RMSE: 54.34

The selection criteria considered the common nature of agricultural operations, the AOI, the use of vehicles, the use of same operational conditions regarding the covered cabin and the use of same operator. Which all contributes to accomplish unified inputs keeping on the realistic implementation behaviour of the operator.

The nature of the selected agricultural operations includes the routine tasks; in which the operator needs to be involved is adding on the mental load due to monitoring of the vehicle track and the accumulated physical fatigue due to checking and monitoring the rear attached and the front mounted tools.

All resulted readings are represented in the modelling part which makes it beneficial to describe some sources of uncertainties. Studying the operator’s behaviour requires to take all readings as to reflect the real situation as much as practically possible.

During the experimental trials the operator used his cell phone listen to some music, making phone calls and even texting. However; being looking to the mobile phone screen with a tool or a dashboard in the background makes it notable for the operator to shuffle his attention when it is required (Fig. 4.18).

Fig. 4.18. Operator using the smartphone during the experimental trials

High values of the root mean square error (RMSE) are noted for some developed models, the justification to such values are related to mission specific issues. The main cause of big differences between the sample value and the next or previous sample is paying an extra attention by the operation to the attached tool and steering at the field edges (Fig. 4.19), in where the operator needs to disengage the attached tool from the operation temporary to make the turn and to steer toward the next bath and thereafter; to re-engage the tool to the operation mode again.

The accumulated gaze time which operator is paying continuously to the tool will be reflected in some samples twice while it is not taken place in the next or the previous sample.

Fig. 4.19. Operator is paying a continuous attention during disengaging the tool from operation

In addition to having different numbers of situations requires more attention from the operator per sample, a notable increase in the accumulated gaze time after the short break time which the operator takes to change the battery of the recording unit and stretch out during the recalibration process (Fig.4.20).

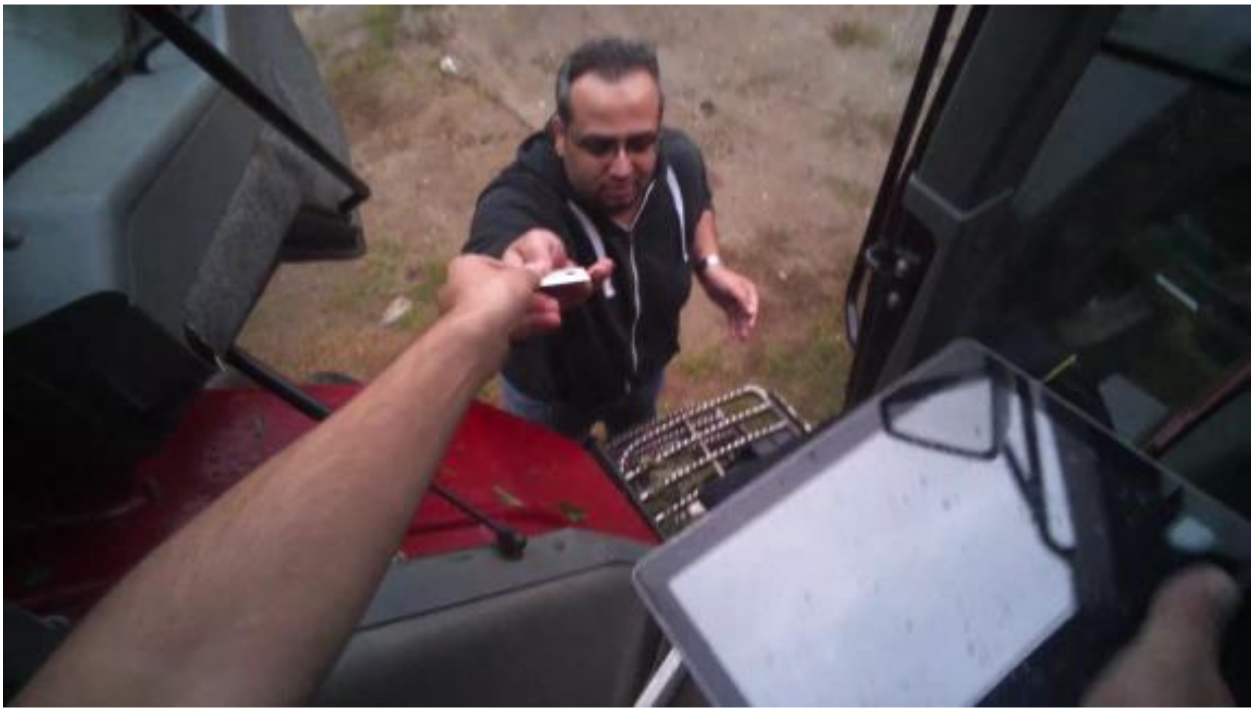


Fig. 4.20. Recalibration process during the recording device battery changing process

Additionally, some operations have some break time for the operator during the process, just like the harvesting agricultural operation during transferring the harvested load to a container emptying the vehicle internal tank (Fig. 4.21).

Fig. 4.21. Transferring the harvested load

In the differences in the resulted models (Fig. 4.22), where the orange arrows are representing the decreasing nature of the operator’s focusing scheme along working hours which is clearly showing the difference of the harvesting operation on the other resulted three curves (two days for cultivating operation and the windrowing operation).

At the beginning of the resulted curves for the windrowing and harvesting models are showing an increment area in prior to starting the decreasing nature of the resulted curves.

While it is noted that, the cultivating operation started in decremental nature for the first few samples of the two resulted models of the same operation along the two working days. Which is shown in (Fig. 4.23), where the blue shaded areas are presenting the increment of operator’s focusing scheme along the few early recorded samples in the windrowing and harvesting agricultural operations, while it is not the situation in the two resulted models for the same agricultural operation of cultivating.

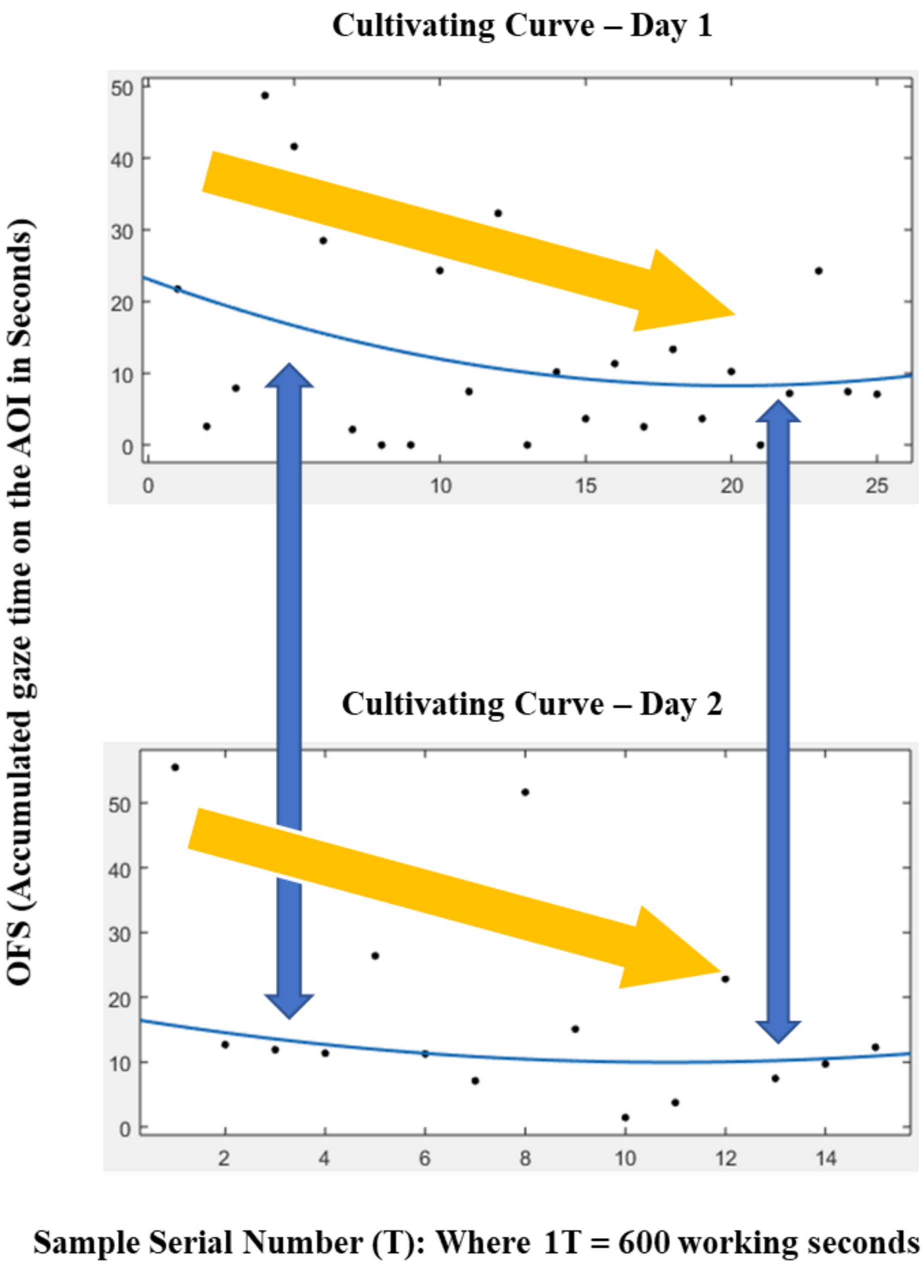


Fig. 4.22. The cultivating models for the 2 working days

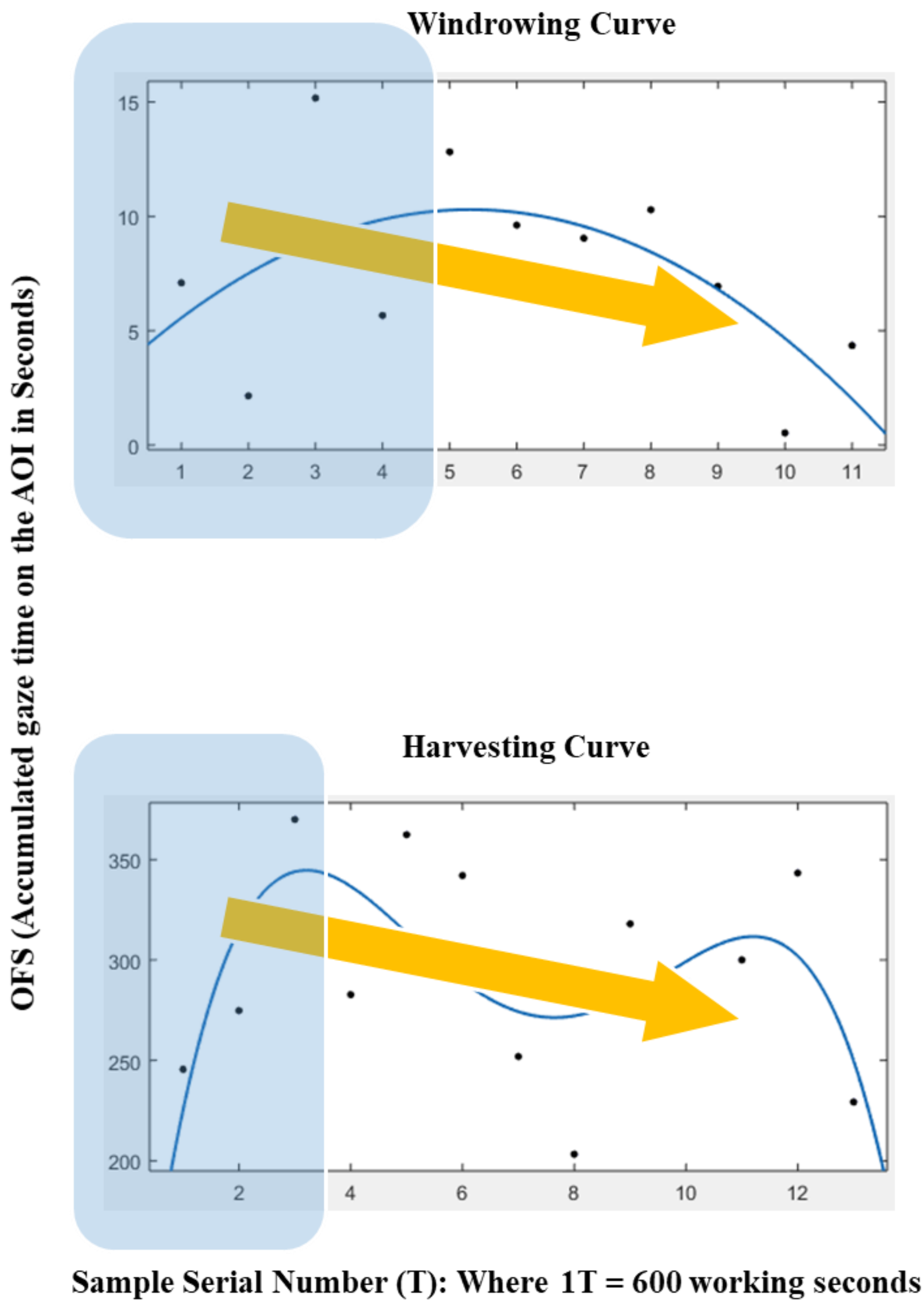
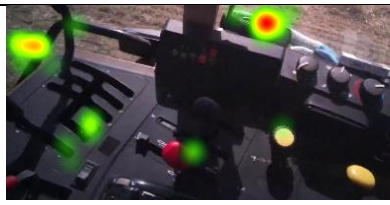


Fig. 4.23. The windrowing and harvesting models

4.6. Least spotted equipment in baling operation

After carrying out the analysis process, the resulted data was exported by the same software to MS Excel sheet which is presented as raw data in Appendix A3 (Tab. A3.4). The exported results (Tab. 4.7) showed the duration along which the operator paid attention to each Item of interest. In addition to the heat maps generated to present distribution of operator gazes inside each area of interest.

Table. 4.7. Experiment results

AOI	**Duration in Seconds**	**Reference snapshot**	**Heat map representing the duration of operator's gaze**
Front dashboard	12.01		
Side panel	31.69		
Left mirror	110.23		
Right mirror	143.24		
Attached tool	139.64		

The analysis of the recorded sample from baling agricultural operation showed that; clearly; the operator spent the most of his time, after the main task of driving and keeping the way on the planned track, in checking the attached tool using the side mirrors and direct check of the attached tool (139.64 + 143.24 + 110.23) which is presenting 26.6% of the total recording time.

In accordance to the validated method, the deterministic data showed; clearly; the least areas of interest equipped the attention of the operator as the percentages showed (Fig. 4.24). Which shows that the dashboard and the side panel AIOs the least Areas of interest during the baling operations.

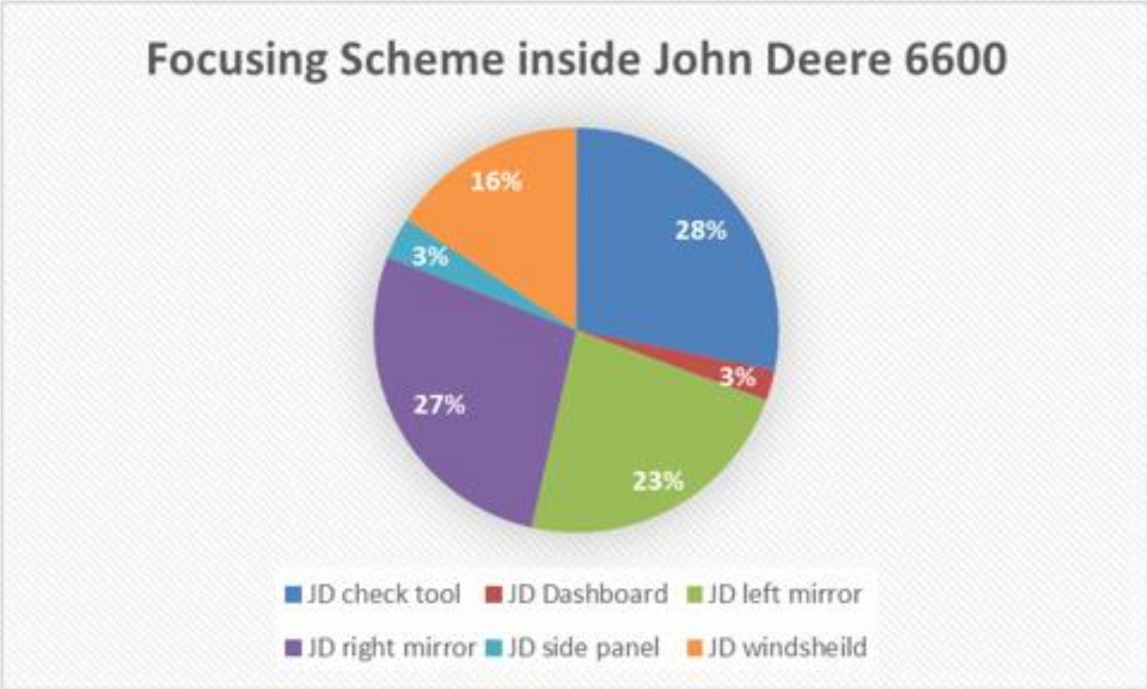


Fig. 4.24. The resulted AOIs percentages for operator's focusing scheme inside John Deere 6600 tractor during baling operation

The methodology of this research is proven to be utilized when and where it is necessary to ensure the safety and productivity of the conducted operation.

The human factor impact on the safety and productivity of the operation is considered very crucial to the success achievement of the planned targets. Aviation field is an obvious example on the importance of the human factor as an essential part of the work mechanism success. Starting of the pilot and cabin crew readiness to handle the accumulated fatigue issue passing through aviation maintenance organizations and the implementation of the right procedure and correctly accomplish all planned activities by technicians and engineers.

4.7. New scientific results

In this section, the unique results; which represent a new contribution to the literature; are presented.

1. Design and validation of the method for measuring the operator's focusing scheme

I have designed the method including procedures and process maps to measure the operator's focusing scheme, and I have utilized the results to create different models for operator's focusing scheme change along working hours in several agricultural operations.

2. The change of operator's focusing scheme along working hours in the windrowing operation

I have collected the results of the operator's gaze on the rear attached windrowing tool, as a selected area of interest, along full working day in the field. I have developed the model describing the change on the OFS along working time in the windrowing agricultural operation, Xwindr (T) where T is the sample number and represents the past 600 working seconds:

$$X\text{windr}(T) = 3.103 + 2.71T - 0.2554T^2$$

3. The change of operator's focusing scheme along working hours in the cultivating operation

I have collected the results of the operator's gaze on the rear attached cultivating tool, as a selected area of interest, along full two working days in the field. I have developed the model describing the change on the OFS along working time in the cultivating agricultural operation, Xcult (T) where T is the sample number and represents the past 600 working seconds:

Day 1 resulted model: $Xcult(T) = 23.10 - 1.480T + 0.03691T^2$

Day 2 resulted model: $Xcult(T) = 16.81 - 1.256T + 0.05763T^2$

4. The change of operator's focusing scheme along working hours in the harvesting operation

I have collected the results of the operator's gaze on the front mounted harvesting tool, as a selected area of interest, along full working day in the field. I have developed the model describing the change on the OFS along working time in the harvesting agricultural operation, Xharv (T) where T is the sample number and represents the past 600 working seconds:

$$Xharv(T) = 43.6 + 239.2T - 63.58T^2 + 6.397T^3 - 0.2175T^4$$

5. The numerical representation of operator's focusing scheme along working hours

I have analyzed the recorded sample from windrowing and cultivating agricultural operation, and I proved the evidential fact, based on deterministic approach, that the operator focusing scheme is decreasing along working hours which is related to the increment of physical and mental load as the time of the agricultural operation conducting. I have demonstrated by numeric representation the trends of operator's focusing scheme change along working hours and its differences based on the nature of the agricultural operation.

6. Defining the least spotted equipment in the baling operation

I have used the developed method to spot the least areas took the attention of the operator inside the tractor cabin in the baling agricultural operation to the purpose of current cabin designs evaluation as well as for comparison purposes following a deterministic approach to support the decision-making process in enhancing current cabins with new technological solutions and for considering that approach during the early design stages of new cabins.

5. CONCLUSIONS AND SUGGESTIONS

In conclusion, the used equipment and supporting software packages easily defined the time in which the operator paid attention to the defined areas of interest during the operations. All experimental trials were conducted in similar environmental and operational conditions. The daylight recording, use of closed cabin controlling the temperature and humidity inside the cabin, protection from dust and insects… etc.; all of it; are considered to be similar along executing all experimental trials in order to keep on consistency of environmental and operational conditions trying to include the same uncertainties sources along all developed models which is reflecting the routine duties conducting by the operator in agricultural operations.

The resulted models can be used to give an indication estimating the effort required by operators to conduct different agricultural operations based on deterministic data driven models.

The impact of the learning process on the operator's focusing scheme is subjected to be under more investigation in order to assess the contribution of the experience of the operator to the production phase in a certain agricultural operation which is proposed to be conducting by developing different models for the same operation executed by different operators with differentiated levels of operating experience.

The resulted models are developed to be used as a simple tool predicting the behavior of an operator inside the off-road vehicle cabins based on deterministic data analysis. The contribution of the implemented models is expected to assist the decision-making process regarding many aspects (i.e. scheduling of breaking times, working hours and payment estimation). Which make it necessary not to exclude any uncertainties expected to accrue during the real-time implementation of the model.

Taking into consideration keeping on the simplicity of the model and not excluding of uncertainties, the resulted models are showing low R^2 coefficient of determinization. This small number is resulted from the huge variation of accumulated operator's gaze from each sample to other samples. Each sample result represents summation of operator's gaze along the 10 minutes of the sample record analysis. Repeating some routine tasks require more operator attention to the AOI might be repeated twice in the same sample while it would not happen in next or previous sample.

However, the resulted models for the tested agricultural operations are found to be the first attempt to modelling the change on operator's focusing scheme along working hours, which is subjected to be improved on a continual base.

The method of research is providing the decision-making process with deterministic data regarding the least and most AOIs sportified by the operator along working hours. Such results are expected to be used to estimate many things including a comparison tool between prototypes of new cabin designs, workload of different operations, operating different vehicles… etc., based on deterministic measures. Additionally; the feasibility of improving cabin designs with new technological solutions based on deterministic data (i.e. cameras and screens instead of mirrors and/or rear cameras to watch the attached tools) in order to reduce the accumulated passive fatigue. Moreover; such a method of research is expected to be used to find out the suitable place to host new components inside the cabin based on the analysis of gaze counts and concentration.

6. SUMMARY

OPERATOR'S FOCUSING SCHEME INSIDE OFF-ROAD VEHICLES

In summary, I have designed the experimental procedures and process maps to execute the full scope of the experimental trials. Firstly; I checked for the required validation for assessing the operator's focusing scheme method before it is used to conduct the real-time experimental trials. And then I developed the extended procedures and process map to manage the results and build the regression models for different agricultural operations.
I have executed the documented experimental procedure along one full day in the field and I developed the model of which representing the change on the OFS along working hours for the windrowing agricultural operation. I have selected the attached rear windrowing tool as an area of interest due to the required physical interaction by the operator to check and steer on a continuous base. I found that; the OFS is decreasing along working hours.

I have developed two models of which representing the change on the OFS along working hours for the cultivating agricultural operation during two working days. Selecting the attached rear cultivating tool as an area of interest due to the required physical interaction by the operator to check and steer on a continuous base. It is found that; the OFS is decreasing; with a similar behavior comparing the two days generated models; along working hours.

I have developed the model of which representing the change on the OFS along working hours for the harvesting agricultural operation. Selecting the front mounted harvesting tool as an area of interest due to the required interaction by the operator to check and steer on a continuous base. It is found that; the OFS is decreasing (in a slower and different behavior than the previous two agricultural operations) along working hours.

I have conducted the analysis of the recorded sample from windrowing and cultivating agricultural operation and it is showed that; clearly; the operator focusing scheme is decreasing along working hours which is related to the increment of physical and mental load as the time of the agricultural operation conducting. While the nature of the harvesting agricultural operation showed a different change on the behavior in which the tool is front mount, however; the operator's focusing scheme showed decreasing behavior in slower trend than other operations in which the rear attached tool which requires relatively more physical effort to turn back and check the rear tool on a continual base, that is correlated to the change in the increment of physical fatigue.

In accordance to the validated method, I have determined; clearly; the least areas of interest equipped the attention of the operator as percentages based on the deterministic data in the baling agricultural operation as an example. And I proved that the developed method is readily to be implemented to the purpose of current cabin designs evaluation as well as for comparison purposes following a deterministic approach to support the decision-making process in enhancing current cabins with new technological solutions and for considering that approach during the early design stages of new cabins.

7. ÖSSZEFOGLALÁS (SUMMARY IN HUNGARIAN)

A GÉPKEZELŐ FIGYELEM MEGOSZLÁSA TEREPEN MOZGÓ JÁRMŰVEK ESETÉBEN

A SZIE Gépészmérnöki Kar Mechanikai és Géptani Intézetének laboratóriumában széles körű kísérleti vizsgálatokat folytattam le, annak érdekében, hogy elvégezzem a szükséges ellenőrzéseket a gépkezelő figyelem megoszlásának kiértékeléséhez.

Megterveztem a kísérleti folyamatokat és folyamat térképeket a kísérleti beállítások teljes körének végrehajtására. Első lépésként a valós idejű kísérleteket megelőzően, elvégeztem a gépkezelő figyelem megoszlása vizsgálati módszerének értékeléséhez szükséges validálást. Ezt követően a kiterjesztett eljárásokat és folyamat térképet dolgoztam ki az eredmények kezelésére és a különböző mezőgazdasági műveletek regressziós modelljeinek meghatározására.

Kifejlesztettem egy olyan modellt, amely segítségével kimutatható, hogy hogyan változik a gépkezelő figyelem megoszlása a munkaidő alatt rendkezelés során. Az erőgép mögött elhelyezett rendkezelő gépet választottam a figyelem megoszlás vizsgálatához. A munkavégzési művelet során a gépkezelőnek mind a kormányzásra (gép irányítása), mind pedig a gép mögötti munkavégző eszközre folyamatosan kell figyelnie. Egyértelműen megállapítottam, hogy a gépkezelő figyelme csökken a munkaidő alatt.

Kidolgoztam két olyan modellt, amelyek segítségével leírható a gépkezelő figyelem megoszlásának változása a munkaidő alatt, kultivátorozási műveletek során. Hátsó függesztett művelőszerszámot választva vizsgáltam a gépkezelő figyelemének változását, annak tükrében, hogy a munkavégzés során a kormányzásra, illetve a művelőszerszámra fordított figyelme hogyan oszlik meg, hogyan változik. A vizsgálatok során két munkanapra vetített modellt készítettem és elemeztem a munkaórák során bekövetkező változást.

Egy modellt dolgoztam ki, amely betakarítási műveletekre bemutatja, hogy a gépkezelő figyelem megoszlása hogyan alakul a munkavégzésre fordított idő függvényében. A betakarítógép elejére szerelt munkavégző eszközt választva vizsgáltam, hogy a munkavégzés során a kormányzásra, illetve a művelőszerszámra fordított figyelme hogyan oszlik meg. Megállapítottam, hogy a gépkezelői figyelem ebben az esetben is csökken a munkaidő függvényében.

Elvégeztem a szoftveresen rögzített kísérleti adatok elemzését a rendkezelés és a kultivátorozás műveletekre. Az eredmények azt mutatták, hogy a munkaidő során egyértelműen csökken a gépkezelő figyelem megoszlása, ami a munkavégzés során bekövetkező fizikai és szellemi terhelés növekedésével függ össze. A betakarítási művelet során a változás más jelleggel megy végbe az kombájn elülső tartószerkezetére felszerelt eszköz miatt; a gépkezelő összpontosítása lassabban csökkenő ütemet mutatott, mint a többi olyan művelet esetén, amelyben a gép mögött elhelyezett művelőeszközök megkövetelik a gépkezelőtől, hogy hátra forduljon. Ez jelentősebb fizikai erőfeszítést igényel és ez a változás korrelációt mutat a fizikai fáradság növekedésével.

A validált módszer szerint példaként meghatároztam és vizsgáltam az egyik legkevesebb figyelmet igénylő területet, a bálázást. Megállapítottam továbbá, hogy a kidolgozott módszert könnyen alkalmazhatjuk traktorfülke tervek értékelésére, valamint összehasonlító célokból is, amely támogatja a döntéshozatali folyamatot az aktuális traktorfülkék új technológiai megoldásokkal történő fejlesztése során, illetve az új kabinok korai tervezési szakaszaiba.

8. APPENDICES

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A2: Publications related to the dissertation

Refereed papers in foreign languages:

1. **Hushki, M.,** Kátai, L., Szabó, I. (2016): Experimental study: operator's behavior measuring inside off-road vehicle cabin (operator's focusing matrix and response time), Mechanical Engineering Research, Vol. 14. 2016., pp. 160-169. HU ISSN 2060-3789 .
2. El-Hagary, E., **Hushki, M.,** Szabo, I. (2017): Fuzzy logic model approaches for water saving in irrigation systems, European Journal of Academic Essays, Vol. 4(4). 2017., pp. 157-165. ISSN 2183-3818
3. Szabó, I., **Hushki, M.,** Bártfai, Z., Kátai, L. (2017): Operator's behavior measuring methodology inside off-road vehicle cabin, operator's focusing scheme, Agronomy Research, Estonia, Vol. 15(5), 2172-2182, 2017. ISSN 1406-894X. (Q2).
4. Szabó, I., **Hushki, M.**, Bártfai, Z., Kátai, L.: Operator's focusing scheme measuring inside a multi-tasking off-road vehicle. In: Hungarian Agricultural Engineering, Vol. 33. 2018., pp. 30-37. HU ISSN 0864-7410 (Print) / HU ISSN 2415-9751(Online) https//:doi.org/10.17676/HAE.2018.32.30
5. Szabó, I., **Hushki, M.,** Bártfai, Z., Lágymányosi, A., and Kátai, L.: Modelling of operator's focusing scheme along working hours: windrowing and cultivating operations, Agronomy Research, Estonia, Vol. 16(4), 1885-1895, 2018. ISSN 1406-894X. (Q2). https://doi.org/10.15159/AR.18.155.
6. Szabó, I., **Hushki, M.,** Bártfai, Z., Lágymányosi, A., and Kátai, L.: Modelling of operator's focusing scheme along working hours: harvesting operation, Agronomy Research, Estonia, 2019. ISSN 1406-894X. (Q2). https://doi.org/10.15159/AR.19.026.

International conference abstracts:

7. Szabó, I., **Hushki, M.,** Bártfai, Z., Kátai, L. (2017): Operator's focusing Scheme measuring inside a multi-tasking off-road vehicle. V. SYNERGY International Conference, V. International Conference of CIGR Hungarian National Committee and the Szent István University, Faculty of Mechanical Engineering and the XXXVIII. R&D Conference of Hungarian Academy of Sciences, Committee of Agricultural and Biosystems Engineering. Gödöllő 16-19. October 2017. Abstracts, p. 83. ISBN 978-963-269-680-5
8. Szabó, I., **Hushki, M.,** Bártfai, Z., Kátai, L. (2017): Operator's behavior measuring methodology inside off-road vehicle cabin, Operator's focusing scheme, Book of Abstracts. 8th International Conference on Biosystems Engineering, Estonian University of Life Sciences, Estonia, p. 102. ISBN: 978-9949-536-81-8
9. Szabó, I., **Hushki, M.,** Bártfai, Z., Kátai, L., Lágymányosi, A. (2018): Examination of the driver's focusing scheme during precision agriciultural operation. In Jakab G., Tóth Ané, Csengeri E.: Alkalmazkodó Vízgazdálkodás: Lehetőségek és kockázatok. Víztudományi Nemzetközi Konferencia. 326 p. Konferencia helye, ideje: Szarvas, Magyarország, 2018.03.22 Szarvas: Szent István Egyetem Agrár- és Gazdaságtudományi Kar, 2018. pp. 1-6. ISBN:978-963-269-736-9

A3: Exported results from Tobii lab pro (the analyzer software)

Table. A3.1: MS Excel sheet which is presented as raw data in the windrowing operation

Average Visit Duration	**Participant**	**Sum**	**Total Time of Interest Duration**	**Total Recording Duration**
sample 1 tool				
Recording004	Csaba Grebely	223.19	600.00	2968.59
Recording005	Rácz Zoltán			1477.95
Recording006	Csaba Grebely			3314.74
Recording008	Csaba Grebely			4023.85
Recording009	Csaba Grebely			1020.07
sample 2 tool				
Recording004	Csaba Grebely	324.56	600.00	2968.59
Recording005	Rácz Zoltán			1477.95
Recording006	Csaba Grebely			3314.74
Recording008	Csaba Grebely			4023.85
Recording009	Csaba Grebely			1020.07
sample 3 tool				
Recording004	Csaba Grebely	412.76	600.00	2968.59
Recording005	Rácz Zoltán			1477.95
Recording006	Csaba Grebely			3314.74
Recording008	Csaba Grebely			4023.85
Recording009	Csaba Grebely			1020.07
sample 4 tool				
Recording004	Csaba Grebely	489.62	600.00	2968.59
Recording005	Rácz Zoltán			1477.95

Recording006	Csaba Grebely			3314.74
Recording008	Csaba Grebely			4023.85
Recording009	Csaba Grebely			1020.07
sample 5 tool				
Recording004	Csaba Grebely	289.63	526.00	2968.59
Recording005	Rácz Zoltán			1477.95
Recording006	Csaba Grebely			3314.74
Recording008	Csaba Grebely			4023.85
Recording009	Csaba Grebely			1020.07
sample 8 tool				
Recording004	Csaba Grebely			2968.59
Recording005	Rácz Zoltán			1477.95
Recording006	Csaba Grebely	205.57	600.00	3314.74
Recording008	Csaba Grebely			4023.85
Recording009	Csaba Grebely			1020.07
sample 9 tool				
Recording004	Csaba Grebely			2968.59
Recording005	Rácz Zoltán			1477.95
Recording006	Csaba Grebely	297.61	600.00	3314.74
Recording008	Csaba Grebely			4023.85
Recording009	Csaba Grebely			1020.07
sample 10 tool				
Recording004	Csaba Grebely			2968.59

Recording005	Rácz Zoltán			1477.95
Recording006	Csaba Grebely	194.95	600.00	3314.74
Recording008	Csaba Grebely			4023.85
Recording009	Csaba Grebely			1020.07
sample 11 tool				
Recording004	Csaba Grebely			2968.59
Recording005	Rácz Zoltán			1477.95
Recording006	Csaba Grebely	262.63	600.00	3314.74
Recording008	Csaba Grebely			4023.85
Recording009	Csaba Grebely			1020.07
sample 12 tool				
Recording004	Csaba Grebely			2968.59
Recording005	Rácz Zoltán			1477.95
Recording006	Csaba Grebely	296.07	720.00	3314.74
Recording008	Csaba Grebely			4023.85
Recording009	Csaba Grebely			1020.07
sample 13 tool				
Recording004	Csaba Grebely			2968.59
Recording005	Rácz Zoltán			1477.95
Recording006	Csaba Grebely			3314.74
Recording008	Csaba Grebely	198.86	585.00	4023.85
Recording009	Csaba Grebely			1020.07
sample 14 tool				
Recording004	Csaba			2968.59

	Grebely			
Recording005	Rácz Zoltán			1477.95
Recording006	Csaba Grebely			3314.74
Recording008	Csaba Grebely	267.83	600.00	4023.85
Recording009	Csaba Grebely			1020.07
sample 15 tool				
Recording004	Csaba Grebely			2968.59
Recording005	Rácz Zoltán			1477.95
Recording006	Csaba Grebely			3314.74
Recording008	Csaba Grebely	671.69	700.00	4023.85
Recording009	Csaba Grebely			1020.07
sample 16 tool				
Recording004	Csaba Grebely			2968.59
Recording005	Rácz Zoltán			1477.95
Recording006	Csaba Grebely			3314.74
Recording008	Csaba Grebely	208.68	600.00	4023.85
Recording009	Csaba Grebely			1020.07
sample 17 tool				
Recording004	Csaba Grebely			2968.59
Recording005	Rácz Zoltán			1477.95
Recording006	Csaba Grebely			3314.74
Recording008	Csaba Grebely	0.09	600.00	4023.85
Recording009	Csaba Grebely			1020.07
sample 18 tool				

Recording004	Csaba Grebely			2968.59
Recording005	Rácz Zoltán			1477.95
Recording006	Csaba Grebely			3314.74
Recording008	Csaba Grebely	136.14	675.00	4023.85
Recording009	Csaba Grebely			1020.07

Table. A3.2: MS Excel sheet which is presented as raw data in the cultivating operation

S14 TOOL				
Average Visit Duration	**Participant**	**TOOL**	**Total Time of Interest Duration**	**Total Recording Duration**
Recording002	Grebely Csaba			744.31
Recording003	Grebely Csaba			4255.42
Recording005	Grebely Csaba			2854.03
Recording006	Grebely Csaba			853.97
Recording007	Grebely Csaba	153.13	780.00	815.42
Recording008	Grebely Csaba			3354.85
Recording009	Grebely Csaba			5848.31
Recording010	Grebely Csaba			6207.40
Recording010	Csaba Grebely			4817.89
Recording011	Grebely Csaba			4359.14
S15 CASE TOOL				
Average Visit Duration	**Participant**	**CASE TOOL**	**Total Time of Interest Duration**	**Total Recording Duration**
Recording002	Grebely Csaba			744.31

Recording003	Grebely Csaba			4255.42
Recording005	Grebely Csaba			2854.03
Recording006	Grebely Csaba			853.97
Recording007	Grebely Csaba			815.42
Recording008	Grebely Csaba	30.29	600.00	3354.85
Recording009	Grebely Csaba			5848.31
Recording010	Grebely Csaba			6207.40
Recording010	Csaba Grebely			4817.89
Recording011	Grebely Csaba			4359.14
S16 CASE TOOL				
Average Visit Duration	**Participant**	**CASE TOOL**	**Total Time of Interest Duration**	**Total Recording Duration**
Recording002	Grebely Csaba			744.31
Recording003	Grebely Csaba			4255.42
Recording005	Grebely Csaba			2854.03
Recording006	Grebely Csaba			853.97
Recording007	Grebely Csaba			815.42
Recording008	Grebely Csaba	140.70	600.00	3354.85
Recording009	Grebely Csaba			5848.31
Recording010	Grebely Csaba			6207.40
Recording010	Csaba Grebely			4817.89
Recording011	Grebely			4359.14

	Csaba			
S17 CASE TOOL				
Average Visit Duration	**Participant**	**CASE TOOL**	**Total Time of Interest Duration**	**Total Recording Duration**
Recording002	Grebely Csaba			744.31
Recording003	Grebely Csaba			4255.42
Recording005	Grebely Csaba			2854.03
Recording006	Grebely Csaba			853.97
Recording007	Grebely Csaba			815.42
Recording008	Grebely Csaba	600.00	600.00	3354.85
Recording009	Grebely Csaba			5848.31
Recording010	Grebely Csaba			6207.40
Recording010	Csaba Grebely			4817.89
Recording011	Grebely Csaba			4359.14
S18 CASE TOOL				
Average Visit Duration	**Participant**	**CASE TOOL**	**Total Time of Interest Duration**	**Total Recording Duration**
Recording002	Grebely Csaba			744.31
Recording003	Grebely Csaba			4255.42
Recording005	Grebely Csaba			2854.03
Recording006	Grebely Csaba			853.97
Recording007	Grebely Csaba			815.42
Recording008	Grebely Csaba	27.56	600.00	3354.85
Recording009	Grebely			5848.31

	Csaba			
Recording010	Grebely Csaba			6207.40
Recording010	Csaba Grebely			4817.89
Recording011	Grebely Csaba			4359.14
S19 CASE TOOL				
Average Visit Duration	**Participant**	**CASE TOOL**	**Total Time of Interest Duration**	**Total Recording Duration**
Recording002	Grebely Csaba			744.31
Recording003	Grebely Csaba			4255.42
Recording005	Grebely Csaba			2854.03
Recording006	Grebely Csaba			853.97
Recording007	Grebely Csaba			815.42
Recording008	Grebely Csaba	51.13	865.00	3354.85
Recording009	Grebely Csaba			5848.31
Recording010	Grebely Csaba			6207.40
Recording010	Csaba Grebely			4817.89
Recording011	Grebely Csaba			4359.14
S20 CASE TOOL				
Average Visit Duration	**Participant**	**CASE TOOL**	**Total Time of Interest Duration**	**Total Recording Duration**
Recording002	Grebely Csaba			744.31
Recording003	Grebely Csaba			4255.42
Recording005	Grebely Csaba			2854.03
Recording006	Grebely			853.97

	Csaba			
Recording007	Grebely Csaba			815.42
Recording008	Grebely Csaba			3354.85
Recording009	Grebely Csaba	108.15	600.00	5848.31
Recording010	Grebely Csaba			6207.40
Recording010	Csaba Grebely			4817.89
Recording011	Grebely Csaba			4359.14
S21 CASE TOOL				
Average Visit Duration	**Participant**	**CASE TOOL**	**Total Time of Interest Duration**	**Total Recording Duration**
Recording002	Grebely Csaba			744.31
Recording003	Grebely Csaba			4255.42
Recording005	Grebely Csaba			2854.03
Recording006	Grebely Csaba			853.97
Recording007	Grebely Csaba			815.42
Recording008	Grebely Csaba			3354.85
Recording009	Grebely Csaba	43.02	600.00	5848.31
Recording010	Grebely Csaba			6207.40
Recording010	Csaba Grebely			4817.89
Recording011	Grebely Csaba			4359.14
S22 CASE TOOL				
Average Visit Duration	**Participant**	**CASE TOOL**	**Total Time of Interest Duration**	**Total Recording Duration**
Recording002	Grebely			744.31

	Csaba			
Recording003	Grebely Csaba			4255.42
Recording005	Grebely Csaba			2854.03
Recording006	Grebely Csaba			853.97
Recording007	Grebely Csaba			815.42
Recording008	Grebely Csaba			3354.85
Recording009	Grebely Csaba	600.00	600.00	5848.31
Recording010	Grebely Csaba			6207.40
Recording010	Csaba Grebely			4817.89
Recording011	Grebely Csaba			4359.14
S23 CASE TOOL				
Average Visit Duration	**Participant**	**CASE TOOL**	**Total Time of Interest Duration**	**Total Recording Duration**
Recording002	Grebely Csaba			744.31
Recording003	Grebely Csaba			4255.42
Recording005	Grebely Csaba			2854.03
Recording006	Grebely Csaba			853.97
Recording007	Grebely Csaba			815.42
Recording008	Grebely Csaba			3354.85
Recording009	Grebely Csaba	600.00	600.00	5848.31
Recording010	Grebely Csaba			6207.40
Recording010	Csaba Grebely			4817.89

Recording011	Grebely Csaba			4359.14
S24 CASE TOOL				
Average Visit Duration	**Participant**	**CASE TOOL**	**Total Time of Interest Duration**	**Total Recording Duration**
Recording002	Grebely Csaba			744.31
Recording003	Grebely Csaba			4255.42
Recording005	Grebely Csaba			2854.03
Recording006	Grebely Csaba			853.97
Recording007	Grebely Csaba			815.42
Recording008	Grebely Csaba			3354.85
Recording009	Grebely Csaba	97.98	600.00	5848.31
Recording010	Grebely Csaba			6207.40
Recording010	Csaba Grebely			4817.89
Recording011	Grebely Csaba			4359.14
S25 CASE TOOL				
Average Visit Duration	**Participant**	**CASE TOOL**	**Total Time of Interest Duration**	**Total Recording Duration**
Recording002	Grebely Csaba			744.31
Recording003	Grebely Csaba			4255.42
Recording005	Grebely Csaba			2854.03
Recording006	Grebely Csaba			853.97
Recording007	Grebely Csaba			815.42
Recording008	Grebely Csaba			3354.85

Recording009	Grebely Csaba	46.07	600.00	5848.31
Recording010	Grebely Csaba			6207.40
Recording010	Csaba Grebely			4817.89
Recording011	Grebely Csaba			4359.14
S26 CASE TOOL				
Average Visit Duration	**Participant**	**CASE TOOL**	**Total Time of Interest Duration**	**Total Recording Duration**
Recording002	Grebely Csaba			744.31
Recording003	Grebely Csaba			4255.42
Recording005	Grebely Csaba			2854.03
Recording006	Grebely Csaba			853.97
Recording007	Grebely Csaba			815.42
Recording008	Grebely Csaba			3354.85
Recording009	Grebely Csaba	35.04	600.00	5848.31
Recording010	Grebely Csaba			6207.40
Recording010	Csaba Grebely			4817.89
Recording011	Grebely Csaba			4359.14
S27 CASE TOOL				
Average Visit Duration	**Participant**	**CASE TOOL**	**Total Time of Interest Duration**	**Total Recording Duration**
Recording002	Grebely Csaba			744.31
Recording003	Grebely Csaba			4255.42
Recording005	Grebely Csaba			2854.03

Recording006	Grebely Csaba			853.97
Recording007	Grebely Csaba			815.42
Recording008	Grebely Csaba			3354.85
Recording009	Grebely Csaba		600.00	5848.31
Recording010	Grebely Csaba			6207.40
Recording010	Csaba Grebely			4817.89
Recording011	Grebely Csaba			4359.14
S28 CASE TOOL				
Average Visit Duration	**Participant**	**CASE TOOL**	**Total Time of Interest Duration**	**Total Recording Duration**
Recording002	Grebely Csaba			744.31
Recording003	Grebely Csaba			4255.42
Recording005	Grebely Csaba			2854.03
Recording006	Grebely Csaba			853.97
Recording007	Grebely Csaba			815.42
Recording008	Grebely Csaba			3354.85
Recording009	Grebely Csaba	2.93	600.00	5848.31
Recording010	Grebely Csaba			6207.40
Recording010	Csaba Grebely			4817.89
Recording011	Grebely Csaba			4359.14
S29 CASE TOOL				
Average Visit Duration	**Participant**	**CASE TOOL**	**Total Time of Interest Duration**	**Total Recording Duration**

Recording002	Grebely Csaba			744.31
Recording003	Grebely Csaba			4255.42
Recording005	Grebely Csaba			2854.03
Recording006	Grebely Csaba			853.97
Recording007	Grebely Csaba			815.42
Recording008	Grebely Csaba			3354.85
Recording009	Grebely Csaba	71.94	420.00	5848.31
Recording010	Grebely Csaba			6207.40
Recording010	Csaba Grebely			4817.89
Recording011	Grebely Csaba			4359.14
S30 CASE TOOL				
Average Visit Duration	**Participant**	**CASE TOOL**	**Total Time of Interest Duration**	**Total Recording Duration**
Recording002	Grebely Csaba			744.31
Recording003	Grebely Csaba			4255.42
Recording005	Grebely Csaba			2854.03
Recording006	Grebely Csaba			853.97
Recording007	Grebely Csaba			815.42
Recording008	Grebely Csaba			3354.85
Recording009	Grebely Csaba			5848.31
Recording010	Grebely Csaba			6207.40
Recording010	Csaba	14.81	600.00	4817.89

	Grebely			
Recording011	Grebely Csaba			4359.14
S31 CASE TOOL				
Average Visit Duration	**Participant**	**CASE TOOL**	**Total Time of Interest Duration**	**Total Recording Duration**
Recording002	Grebely Csaba			744.31
Recording003	Grebely Csaba			4255.42
Recording005	Grebely Csaba			2854.03
Recording006	Grebely Csaba			853.97
Recording007	Grebely Csaba			815.42
Recording008	Grebely Csaba			3354.85
Recording009	Grebely Csaba			5848.31
Recording010	Grebely Csaba			6207.40
Recording010	Csaba Grebely	75.17	600.00	4817.89
Recording011	Grebely Csaba			4359.14
S32 CASE TOOL				
Average Visit Duration	**Participant**	**CASE TOOL**	**Total Time of Interest Duration**	**Total Recording Duration**
Recording002	Grebely Csaba			744.31
Recording003	Grebely Csaba			4255.42
Recording005	Grebely Csaba			2854.03
Recording006	Grebely Csaba			853.97
Recording007	Grebely Csaba			815.42
Recording008	Grebely			3354.85

	Csaba			
Recording009	Grebely Csaba			5848.31
Recording010	Grebely Csaba			6207.40
Recording010	Csaba Grebely	85.46	600.00	4817.89
Recording011	Grebely Csaba			4359.14
S33 CASE TOOL				
Average Visit Duration	**Participant**	**CASE TOOL**	**Total Time of Interest Duration**	**Total Recording Duration**
Recording002	Grebely Csaba			744.31
Recording003	Grebely Csaba			4255.42
Recording005	Grebely Csaba			2854.03
Recording006	Grebely Csaba			853.97
Recording007	Grebely Csaba			815.42
Recording008	Grebely Csaba			3354.85
Recording009	Grebely Csaba			5848.31
Recording010	Grebely Csaba			6207.40
Recording010	Csaba Grebely	55.89	600.00	4817.89
Recording011	Grebely Csaba			4359.14
S34 CASE TOOL				
Average Visit Duration	**Participant**	**CASE TOOL**	**Total Time of Interest Duration**	**Total Recording Duration**
Recording002	Grebely Csaba			744.31
Recording003	Grebely Csaba			4255.42
Recording005	Grebely			2854.03

	Csaba			
Recording006	Grebely Csaba			853.97
Recording007	Grebely Csaba			815.42
Recording008	Grebely Csaba			3354.85
Recording009	Grebely Csaba			5848.31
Recording010	Grebely Csaba			6207.40
Recording010	Csaba Grebely	53.33	600.00	4817.89
Recording011	Grebely Csaba			4359.14
S35 CASE TOOL				
Average Visit Duration	**Participant**	**CASE TOOL**	**Total Time of Interest Duration**	**Total Recording Duration**
Recording002	Grebely Csaba			744.31
Recording003	Grebely Csaba			4255.42
Recording005	Grebely Csaba			2854.03
Recording006	Grebely Csaba			853.97
Recording007	Grebely Csaba			815.42
Recording008	Grebely Csaba			3354.85
Recording009	Grebely Csaba			5848.31
Recording010	Grebely Csaba			6207.40
Recording010	Csaba Grebely	33.88	600.00	4817.89
Recording011	Grebely Csaba			4359.14
S36 CASE TOOL				
Average Visit	**Participant**	**CASE**	**Total Time of**	**Total Recording**

Duration		**TOOL**	**Interest Duration**	**Duration**
Recording002	Grebely Csaba			744.31
Recording003	Grebely Csaba			4255.42
Recording005	Grebely Csaba			2854.03
Recording006	Grebely Csaba			853.97
Recording007	Grebely Csaba			815.42
Recording008	Grebely Csaba			3354.85
Recording009	Grebely Csaba			5848.31
Recording010	Grebely Csaba			6207.40
Recording010	Csaba Grebely	25.65	600.00	4817.89
Recording011	Grebely Csaba			4359.14
S37 CASE TOOL				
Average Visit Duration	**Participant**	**CASE TOOL**	**Total Time of Interest Duration**	**Total Recording Duration**
Recording002	Grebely Csaba			744.31
Recording003	Grebely Csaba			4255.42
Recording005	Grebely Csaba			2854.03
Recording006	Grebely Csaba			853.97
Recording007	Grebely Csaba			815.42
Recording008	Grebely Csaba			3354.85
Recording009	Grebely Csaba			5848.31
Recording010	Grebely Csaba			6207.40

Recording010	Csaba Grebely	40.74	570.00	4817.89
Recording011	Grebely Csaba			4359.14
S38 CASE TOOL				
Average Visit Duration	**Participant**	**CASE TOOL**	**Total Time of Interest Duration**	**Total Recording Duration**
Recording002	Grebely Csaba			744.31
Recording003	Grebely Csaba			4255.42
Recording005	Grebely Csaba			2854.03
Recording006	Grebely Csaba			853.97
Recording007	Grebely Csaba			815.42
Recording008	Grebely Csaba			3354.85
Recording009	Grebely Csaba			5848.31
Recording010	Grebely Csaba	79.67	600.00	6207.40
Recording010	Csaba Grebely			4817.89
Recording011	Grebely Csaba			4359.14
S39 CASE TOOL				
Average Visit Duration	**Participant**	**CASE TOOL**	**Total Time of Interest Duration**	**Total Recording Duration**
Recording002	Grebely Csaba			744.31
Recording003	Grebely Csaba			4255.42
Recording005	Grebely Csaba			2854.03
Recording006	Grebely Csaba			853.97
Recording007	Grebely Csaba			815.42

Recording008	Grebely Csaba			3354.85
Recording009	Grebely Csaba			5848.31
Recording010	Grebely Csaba	550.13	600.00	6207.40
Recording010	Csaba Grebely			4817.89
Recording011	Grebely Csaba			4359.14
S40 CASE TOOL				
Average Visit Duration	**Participant**	**CASE TOOL**	**Total Time of Interest Duration**	**Total Recording Duration**
Recording002	Grebely Csaba			744.31
Recording003	Grebely Csaba			4255.42
Recording005	Grebely Csaba			2854.03
Recording006	Grebely Csaba			853.97
Recording007	Grebely Csaba			815.42
Recording008	Grebely Csaba			3354.85
Recording009	Grebely Csaba			5848.31
Recording010	Grebely Csaba	59.26	600.00	6207.40
Recording010	Csaba Grebely			4817.89
Recording011	Grebely Csaba			4359.14
S41 CASE TOOL				
Average Visit Duration	**Participant**	**CASE TOOL**	**Total Time of Interest Duration**	**Total Recording Duration**
Recording002	Grebely Csaba			744.31
Recording003	Grebely Csaba			4255.42

Recording005	Grebely Csaba			2854.03
Recording006	Grebely Csaba			853.97
Recording007	Grebely Csaba			815.42
Recording008	Grebely Csaba			3354.85
Recording009	Grebely Csaba			5848.31
Recording010	Grebely Csaba	183.87	600.00	6207.40
Recording010	Csaba Grebely			4817.89
Recording011	Grebely Csaba			4359.14
S42 CASE TOOL				
Average Visit Duration	**Participant**	**CASE TOOL**	**Total Time of Interest Duration**	**Total Recording Duration**
Recording002	Grebely Csaba			744.31
Recording003	Grebely Csaba			4255.42
Recording005	Grebely Csaba			2854.03
Recording006	Grebely Csaba			853.97
Recording007	Grebely Csaba			815.42
Recording008	Grebely Csaba			3354.85
Recording009	Grebely Csaba			5848.31
Recording010	Grebely Csaba	141.35	600.00	6207.40
Recording010	Csaba Grebely			4817.89
Recording011	Grebely Csaba			4359.14
S43 CASE TOOL				

Average Visit Duration	**Participant**	**CASE TOOL**	**Total Time of Interest Duration**	**Total Recording Duration**
Recording002	Grebely Csaba			744.31
Recording003	Grebely Csaba			4255.42
Recording005	Grebely Csaba			2854.03
Recording006	Grebely Csaba			853.97
Recording007	Grebely Csaba			815.42
Recording008	Grebely Csaba			3354.85
Recording009	Grebely Csaba			5848.31
Recording010	Grebely Csaba	600.00	600.00	6207.40
Recording010	Csaba Grebely			4817.89
Recording011	Grebely Csaba			4359.14
S44 CASE TOOL				
Average Visit Duration	**Participant**	**CASE TOOL**	**Total Time of Interest Duration**	**Total Recording Duration**
Recording002	Grebely Csaba			744.31
Recording003	Grebely Csaba			4255.42
Recording005	Grebely Csaba			2854.03
Recording006	Grebely Csaba			853.97
Recording007	Grebely Csaba			815.42
Recording008	Grebely Csaba			3354.85
Recording009	Grebely Csaba			5848.31
Recording010	Grebely	600.00	600.00	6207.40

	Csaba			
Recording010	Csaba Grebely			4817.89
Recording011	Grebely Csaba			4359.14
S45 CASE TOOL				
Average Visit Duration	**Participant**	**CASE TOOL**	**Total Time of Interest Duration**	**Total Recording Duration**
Recording002	Grebely Csaba			744.31
Recording003	Grebely Csaba			4255.42
Recording005	Grebely Csaba			2854.03
Recording006	Grebely Csaba			853.97
Recording007	Grebely Csaba			815.42
Recording008	Grebely Csaba			3354.85
Recording009	Grebely Csaba			5848.31
Recording010	Grebely Csaba	49.39	600.00	6207.40
Recording010	Csaba Grebely			4817.89
Recording011	Grebely Csaba			4359.14
S46 CASE TOOL				
Average Visit Duration	**Participant**	**CASE TOOL**	**Total Time of Interest Duration**	**Total Recording Duration**
Recording002	Grebely Csaba			744.31
Recording003	Grebely Csaba			4255.42
Recording005	Grebely Csaba			2854.03
Recording006	Grebely Csaba			853.97
Recording007	Grebely			815.42

	Csaba			
Recording008	Grebely Csaba			3354.85
Recording009	Grebely Csaba			5848.31
Recording010	Grebely Csaba	198.84	600.00	6207.40
Recording010	Csaba Grebely			4817.89
Recording011	Grebely Csaba			4359.14
S47 CASE TOOL				
Average Visit Duration	**Participant**	**CASE TOOL**	**Total Time of Interest Duration**	**Total Recording Duration**
Recording002	Grebely Csaba			744.31
Recording003	Grebely Csaba			4255.42
Recording005	Grebely Csaba			2854.03
Recording006	Grebely Csaba			853.97
Recording007	Grebely Csaba			815.42
Recording008	Grebely Csaba			3354.85
Recording009	Grebely Csaba			5848.31
Recording010	Grebely Csaba	56.81	720.00	6207.40
Recording010	Csaba Grebely			4817.89
Recording011	Grebely Csaba			4359.14
S48 CASE TOOL				
Average Visit Duration	**Participant**	**CASE TOOL**	**Total Time of Interest Duration**	**Total Recording Duration**
Recording002	Grebely Csaba			744.31
Recording003	Grebely			4255.42

	Csaba			
Recording005	Grebely Csaba			2854.03
Recording006	Grebely Csaba			853.97
Recording007	Grebely Csaba			815.42
Recording008	Grebely Csaba			3354.85
Recording009	Grebely Csaba			5848.31
Recording010	Grebely Csaba			6207.40
Recording010	Csaba Grebely			4817.89
Recording011	Grebely Csaba	52.18	600.00	4359.14
S49 CASE TOOL				
Average Visit Duration	**Participant**	**CASE TOOL**	**Total Time of Interest Duration**	**Total Recording Duration**
Recording002	Grebely Csaba			744.31
Recording003	Grebely Csaba			4255.42
Recording005	Grebely Csaba			2854.03
Recording006	Grebely Csaba			853.97
Recording007	Grebely Csaba			815.42
Recording008	Grebely Csaba			3354.85
Recording009	Grebely Csaba			5848.31
Recording010	Grebely Csaba			6207.40
Recording010	Csaba Grebely			4817.89
Recording011	Grebely Csaba	498.59	600.00	4359.14

S50 CASE TOOL				
Average Visit Duration	**Participant**	**CASE TOOL**	**Total Time of Interest Duration**	**Total Recording Duration**
Recording002	Grebely Csaba			744.31
Recording003	Grebely Csaba			4255.42
Recording005	Grebely Csaba			2854.03
Recording006	Grebely Csaba			853.97
Recording007	Grebely Csaba			815.42
Recording008	Grebely Csaba			3354.85
Recording009	Grebely Csaba			5848.31
Recording010	Grebely Csaba			6207.40
Recording010	Csaba Grebely			4817.89
Recording011	Grebely Csaba	18.46	600.00	4359.14
S51 CASE TOOL				
Average Visit Duration	**Participant**	**CASE TOOL**	**Total Time of Interest Duration**	**Total Recording Duration**
Recording002	Grebely Csaba			744.31
Recording003	Grebely Csaba			4255.42
Recording005	Grebely Csaba			2854.03
Recording006	Grebely Csaba			853.97
Recording007	Grebely Csaba			815.42
Recording008	Grebely Csaba			3354.85
Recording009	Grebely Csaba			5848.31

Recording010	Grebely Csaba			6207.40
Recording010	Csaba Grebely			4817.89
Recording011	Grebely Csaba	26.10	600.00	4359.14
S52 CASE TOOL				
Average Visit Duration	**Participant**	**CASE TOOL**	**Total Time of Interest Duration**	**Total Recording Duration**
Recording002	Grebely Csaba			744.31
Recording003	Grebely Csaba			4255.42
Recording005	Grebely Csaba			2854.03
Recording006	Grebely Csaba			853.97
Recording007	Grebely Csaba			815.42
Recording008	Grebely Csaba			3354.85
Recording009	Grebely Csaba			5848.31
Recording010	Grebely Csaba			6207.40
Recording010	Csaba Grebely			4817.89
Recording011	Grebely Csaba	166.48	600.00	4359.14
S53 CASE TOOL				
Average Visit Duration	**Participant**	**CASE TOOL**	**Total Time of Interest Duration**	**Total Recording Duration**
Recording002	Grebely Csaba			744.31
Recording003	Grebely Csaba			4255.42
Recording005	Grebely Csaba			2854.03
Recording006	Grebely Csaba			853.97

Recording007	Grebely Csaba			815.42
Recording008	Grebely Csaba			3354.85
Recording009	Grebely Csaba			5848.31
Recording010	Grebely Csaba			6207.40
Recording010	Csaba Grebely			4817.89
Recording011	Grebely Csaba	121.84	600.00	4359.14
S54 CASE TOOL				
Average Visit Duration	**Participant**	**CASE TOOL**	**Total Time of Interest Duration**	**Total Recording Duration**
Recording002	Grebely Csaba			744.31
Recording003	Grebely Csaba			4255.42
Recording005	Grebely Csaba			2854.03
Recording006	Grebely Csaba			853.97
Recording007	Grebely Csaba			815.42
Recording008	Grebely Csaba			3354.85
Recording009	Grebely Csaba			5848.31
Recording010	Grebely Csaba			6207.40
Recording010	Csaba Grebely			4817.89
Recording011	Grebely Csaba	218.38	600.00	4359.14

Table. A3.3: MS Excel sheet which is presented as raw data in the harvesting operation

S01 FRONT TOOL				
Average Visit Duration	**Participant**	**FRONT TOOL AOI**	**Total Time of Interest Duration**	**Total Recording Duration**

Recording002	Grebely Csaba	2.25	670.00	744.31
Recording003	Grebely Csaba			4255.42
Recording005	Grebely Csaba			2854.03
Recording006	Grebely Csaba			853.97
Recording007	Grebely Csaba			815.42
Recording008	Grebely Csaba			3354.85
Recording009	Grebely Csaba			5848.31
Recording010	Grebely Csaba			6207.40
Recording010	Csaba Grebely			4817.89
Recording011	Grebely Csaba			4359.14
S02 FRONT TOOL				
Average Visit Duration	**Participant**	**FRONT TOOL AOI**	**Total Time of Interest Duration**	**Total Recording Duration**
Recording002	Grebely Csaba			744.31
Recording003	Grebely Csaba	3.60	600.00	4255.42
Recording005	Grebely Csaba			2854.03
Recording006	Grebely Csaba			853.97
Recording007	Grebely Csaba			815.42
Recording008	Grebely Csaba			3354.85
Recording009	Grebely Csaba			5848.31
Recording010	Grebely Csaba			6207.40
Recording010	Csaba			4817.89

	Grebely			
Recording011	Grebely Csaba			4359.14
S03 FRONT TOOL				
Average Visit Duration	**Participant**	**FRONT TOOL AOI**	**Total Time of Interest Duration**	**Total Recording Duration**
Recording002	Grebely Csaba			744.31
Recording003	Grebely Csaba	4.63	600.00	4255.42
Recording005	Grebely Csaba			2854.03
Recording006	Grebely Csaba			853.97
Recording007	Grebely Csaba			815.42
Recording008	Grebely Csaba			3354.85
Recording009	Grebely Csaba			5848.31
Recording010	Grebely Csaba			6207.40
Recording010	Csaba Grebely			4817.89
Recording011	Grebely Csaba			4359.14
S04 FRONT TOOL				
Average Visit Duration	**Participant**	**FRONT TOOL AOI**	**Total Time of Interest Duration**	**Total Recording Duration**
Recording002	Grebely Csaba			744.31
Recording003	Grebely Csaba	3.04	600.00	4255.42
Recording005	Grebely Csaba			2854.03
Recording006	Grebely Csaba			853.97
Recording007	Grebely Csaba			815.42
Recording008	Grebely			3354.85

	Csaba			
Recording009	Grebely Csaba			5848.31
Recording010	Grebely Csaba			6207.40
Recording010	Csaba Grebely			4817.89
Recording011	Grebely Csaba			4359.14
S05 FRONT TOOL				
Average Visit Duration	**Participant**	**FRONT TOOL AOI**	**Total Time of Interest Duration**	**Total Recording Duration**
Recording002	Grebely Csaba			744.31
Recording003	Grebely Csaba	2.16	600.00	4255.42
Recording005	Grebely Csaba			2854.03
Recording006	Grebely Csaba			853.97
Recording007	Grebely Csaba			815.42
Recording008	Grebely Csaba			3354.85
Recording009	Grebely Csaba			5848.31
Recording010	Grebely Csaba			6207.40
Recording010	Csaba Grebely			4817.89
Recording011	Grebely Csaba			4359.14
S06 FRONT TOOL				
Average Visit Duration	**Participant**	**FRONT TOOL AOI**	**Total Time of Interest Duration**	**Total Recording Duration**
Recording002	Grebely Csaba			744.31
Recording003	Grebely Csaba	4.20	600.00	4255.42
Recording005	Grebely			2854.03

	Csaba			
Recording006	Grebely Csaba			853.97
Recording007	Grebely Csaba			815.42
Recording008	Grebely Csaba			3354.85
Recording009	Grebely Csaba			5848.31
Recording010	Grebely Csaba			6207.40
Recording010	Csaba Grebely			4817.89
Recording011	Grebely Csaba			4359.14
S07 FRONT TOOL				
Average Visit Duration	**Participant**	**FRONT TOOL AOI**	**Total Time of Interest Duration**	**Total Recording Duration**
Recording002	Grebely Csaba			744.31
Recording003	Grebely Csaba	3.35	600.00	4255.42
Recording005	Grebely Csaba			2854.03
Recording006	Grebely Csaba			853.97
Recording007	Grebely Csaba			815.42
Recording008	Grebely Csaba			3354.85
Recording009	Grebely Csaba			5848.31
Recording010	Grebely Csaba			6207.40
Recording010	Csaba Grebely			4817.89
Recording011	Grebely Csaba			4359.14
S08 FRONT TOOL				
Average Visit	**Participant**	**FRONT**	**Total Time of**	**Total Recording**

Duration		**TOOL AOI**	**Interest Duration**	**Duration**
Recording002	Grebely Csaba			744.31
Recording003	Grebely Csaba	3.62	585.00	4255.42
Recording005	Grebely Csaba			2854.03
Recording006	Grebely Csaba			853.97
Recording007	Grebely Csaba			815.42
Recording008	Grebely Csaba			3354.85
Recording009	Grebely Csaba			5848.31
Recording010	Grebely Csaba			6207.40
Recording010	Csaba Grebely			4817.89
Recording011	Grebely Csaba			4359.14
S09 FRONT TOOL				
Average Visit Duration	**Participant**	**FRONT TOOL AOI**	**Total Time of Interest Duration**	**Total Recording Duration**
Recording002	Grebely Csaba			744.31
Recording003	Grebely Csaba			4255.42
Recording005	Grebely Csaba	5.08	600.00	2854.03
Recording006	Grebely Csaba			853.97
Recording007	Grebely Csaba			815.42
Recording008	Grebely Csaba			3354.85
Recording009	Grebely Csaba			5848.31
Recording010	Grebely Csaba			6207.40

Recording010	Csaba Grebely			4817.89
Recording011	Grebely Csaba			4359.14
S10 FRONT TOOL				
Average Visit Duration	**Participant**	**FRONT TOOL AOI**	**Total Time of Interest Duration**	**Total Recording Duration**
Recording002	Grebely Csaba			744.31
Recording003	Grebely Csaba			4255.42
Recording005	Grebely Csaba	9.24	600.00	2854.03
Recording006	Grebely Csaba			853.97
Recording007	Grebely Csaba			815.42
Recording008	Grebely Csaba			3354.85
Recording009	Grebely Csaba			5848.31
Recording010	Grebely Csaba			6207.40
Recording010	Csaba Grebely			4817.89
Recording011	Grebely Csaba			4359.14
S11 FRONT TOOL				
Average Visit Duration	**Participant**	**FRONT TOOL AOI**	**Total Time of Interest Duration**	**Total Recording Duration**
Recording002	Grebely Csaba			744.31
Recording003	Grebely Csaba			4255.42
Recording005	Grebely Csaba	4.35	600.00	2854.03
Recording006	Grebely Csaba			853.97
Recording007	Grebely Csaba			815.42

Recording008	Grebely Csaba			3354.85
Recording009	Grebely Csaba			5848.31
Recording010	Grebely Csaba			6207.40
Recording010	Csaba Grebely			4817.89
Recording011	Grebely Csaba			4359.14
S12 FRONT TOOL				
Average Visit Duration	**Participant**	**FRONT TOOL AOI**	**Total Time of Interest Duration**	**Total Recording Duration**
Recording002	Grebely Csaba			744.31
Recording003	Grebely Csaba			4255.42
Recording005	Grebely Csaba	3.51	600.00	2854.03
Recording006	Grebely Csaba			853.97
Recording007	Grebely Csaba			815.42
Recording008	Grebely Csaba			3354.85
Recording009	Grebely Csaba			5848.31
Recording010	Grebely Csaba			6207.40
Recording010	Csaba Grebely			4817.89
Recording011	Grebely Csaba			4359.14
S13 FRONT TOOL				
Average Visit Duration	**Participant**	**FRONT TOOL AOI**	**Total Time of Interest Duration**	**Total Recording Duration**
Recording002	Grebely Csaba			744.31
Recording003	Grebely Csaba			4255.42

Recording005	Grebely Csaba	2.59	449.00	2854.03
Recording006	Grebely Csaba			853.97
Recording007	Grebely Csaba			815.42
Recording008	Grebely Csaba			3354.85
Recording009	Grebely Csaba			5848.31
Recording010	Grebely Csaba			6207.40
Recording010	Csaba Grebely			4817.89
Recording011	Grebely Csaba			4359.14

Table. A3.4: MS Excel sheet which is presented as raw data inside the John Deere tractor cabin during the baling operation

Average Visit Duration	**Participant**	**Sum**	**Total Time of Interest Duration**	**Total Recording Duration**
JD check tool				
Recording004	Csaba Grebely			2968.59
Recording005	Rácz Zoltán	67.40	139.64	1477.95
Recording006	Csaba Grebely			3314.74
Recording008	Csaba Grebely			4023.85
Recording009	Csaba Grebely			1020.07
JD Dashboard				
Recording004	Csaba Grebely			2968.59
Recording005	Rácz Zoltán	11.67	12.01	1477.95
Recording006	Csaba Grebely			3314.74
Recording008	Csaba Grebely			4023.85

Recording009	Csaba Grebely			1020.07
JD left mirror				
Recording004	Csaba Grebely			2968.59
Recording005	Rácz Zoltán	109.71	110.23	1477.95
Recording006	Csaba Grebely			3314.74
Recording008	Csaba Grebely			4023.85
Recording009	Csaba Grebely			1020.07
JD right mirror				
Recording004	Csaba Grebely			2968.59
Recording005	Rácz Zoltán	32.68	143.24	1477.95
Recording006	Csaba Grebely			3314.74
Recording008	Csaba Grebely			4023.85
Recording009	Csaba Grebely			1020.07
JD side panel				
Recording004	Csaba Grebely			2968.59
Recording005	Rácz Zoltán	3.19	31.69	1477.95
Recording006	Csaba Grebely			3314.74
Recording008	Csaba Grebely			4023.85
Recording009	Csaba Grebely			1020.07
JD windshield				
Recording004	Csaba Grebely			2968.59
Recording005	Rácz Zoltán	75.52	75.54	1477.95
Recording006	Csaba Grebely			3314.74
Recording008	Csaba			4023.85

	Grebely			
Recording009	Csaba Grebely			1020.07

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