Work Economic and Ergonomic Effects of GNSS Guidance Systems

M. Holpp [1]; M. Kroulik [2]; Z. Kviz [2]; T. Anken [1]; M. Sauter [1] and O. Hensel [3]

[1] Agroscope Research Station, Department of Agricultural Economics and Engineering Tänikon 1, 8356 Ettenhausen, Switzerland, martin.holpp@agroscope.admin.ch; [2] Czech University of Life Sciences, Department of Agricultural Machines, Prague, Czech Republic; [3] Kassel University, Agricultural Engineering, Witzenhausen, Germany

ABSTRACT

Positive driving performance and ergonomic effects are ascribed to satellite-based automatic guidance systems. Although the literature had provided some information on working-width utilisation, turning-time requirement and steering accuracy, the relevant studies had mostly been carried out on smaller areas of land under experimental conditions. Little information was found on the nearly-always-mentioned reduction in driver workload. A large-scale field trial under practical conditions was carried out in the Czech Republic for the expanded clarification of the driving-performance and ergonomic effects of automatic guidance systems. Various parameters were recorded for 17 drivers with respect to primary tillage, seedbed preparation and sowing both with and without a guidance system. Working widths were between 5 and 15 m, and field sizes between 1.2 and 15.7 ha. The findings showed that driving speeds, turning times and working-width utilisation were in some cases more advantageous with a guidance system, but did not differ statistically significantly. The variations caused by driver, field shape and field margins had a greater influence than the use of guidance systems. However, two parameters differed significantly. Guidance systems increased average steering accuracy and delivered lower heart rates. The study confirmed that guidance systems can deliver positive driving performance effects and driver relief.

Keywords: Satellite guidance, drive performance, ergonomics, Switzerland

1. INTRODUCTION

Agricultural guidance systems, based on Global Navigation Satellite Systems (GNSS), are said to deliver advantages compared to manual steering, e.g. better use of working width, better steering quality, less stress for the driver, time savings due to optimized turnovers in the headland etc. A literature review delivered some information on various parameters (Demmel, 2007; Keller, 2005; Kroulik, Kumhala, Hula, & Honzik, 2009; Niemann, Schwaiberger, & Fröba, 2007). No scientific data were found about the mentioned stress reduction for the driver. In order to enhance the knowledge about work economic and ergonomic effects of GNSS guidance systems a large scale field experiment was set up (Holpp, Kroulik, Kviz, Anken, & Sauter, 2012).

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2. MATERIALS AND METHODS

2.1 Trial design

The surveys on primary tillage, seedbed preparation and sowing took place in autumn 2010 and spring 2011 on commercial farms in various regions of the Czech Republic with a total of 17 drivers. Drivers were male and between 20 and 60 years old, the average was 34 years. The equipment used for primary tillage had working widths of 5-15 m, whilst the figure was 8 m for seedbed preparation and 6-9 m for sowing. The seed drills were equipped with track markers, whilst the primary-tillage equipment had no additional markers. 66 plots ranging from 1.2 to 15.7 ha in size were considered in the analysis, with the average being 5.7 ha and the median 4.9 ha. Total surface area was 373 ha. A sampling ratio of about 50 % without and 50 % with guidance system was aimed at. On all tractors satellite-based automatic guidance systems EZ-Guide 500 (Trimble, Sunnyvale, California, USA) with Real Time Kinematic Network correction (AgCelNet, Leading Farmers CZ a.s., Prague, Czech Republic) and an accuracy of +/- 0.025 m were used. One tractor was equipped with aa Trimble EZ-Steer device mounted to the steering wheel, all others with a Trimble Autopilot being integrated in the vehicle's steering hydraulics. Vehicles drove in straight parallel lines on all fields, except for one, where the vehicle followed the previous curved lane. Turning mode was chosen by the drivers according to the on-site conditions. Without a guidance system, omega curves were always used; with a guidance system, either omega curves or a lane-skipping approach was used. During the turning operation, the driver steered manually and headed towards the next tramline according to the on-screen information. Measurements were spread out over the day from 7 am to 12 midnight. No automatic cruise control (Tempomat) which might have influenced the results was used. In order to avoid disturbances during measurement, no one was allowed on the tractor except for the driver. Guidance-system positions were recorded with a data logger (DD-Logger, CSM, Filderstadt, Germany) with a recording rate of 1 Hz. For the heart-rate measurements, sports watches (Polar RS800CX, Kempele, Finland) with a chest-strap sensor and a polar satellite receiver (Polar G3 GPS Sensor, Kempele, Finland) with a position accuracy of +/- 0.3 m were used.

2.2 Study parameters

The field was subdivided into headland and main area. The turning operations took place in the headland, whilst the machine was in operation in the main area. The following parameters were investigated without/with the use of the guidance system during the primary tillage, seedbed preparation and sowing operations:

- **Driving speeds** in the main area and headland, based on the average values of the drivers.
- **Turning times**, based on the individual turning operations.
- **Steering accuracy** in the main area, based on the deviation from the target tramline calculated from the position points for the individual tramlines.

- **Utilisation of vehicle working width** based on field width, working width, and number of tramlines driven.
- As a measure of driver stress and relief, the **heart rates** in the main area and headland, based on the averages of the drivers.

2.3 Data analysis

For data processing Arc-GIS (Version 9.2, ESRI, Redlands, California, USA), QGIS (Quantum GIS Version 1.02, Open Source Geospatial Foundation (OSGeo), Beaverton, Oregon, USA) and Excel 2007 (Microsoft, Redmond, Washington, USA) were employed. As mentioned above, a position point was stored every second on the route travelled by the tractor. The tilled field was then available as a point cloud. The chronological connection of the points showed the driving route. In order to determine the headland and main area, the corresponding points were stored separately in the GIS. Because of this separation of the route, the position points were no longer available in continuos second intervals. Time leaps occur where the headland and main area were separated. A time difference of > 1 s indicates the beginning of a new tramline or a new turning operation. In this way, tramlines and turning operations were counted and **turning times** were deduced. **Driving speeds** are contained in the satellite position data, and averages were created for the tramlines and turning operations. To determine **steering accuracy**, the straight line of regression (= target tramline) was calculated from the position points of the individual tramlines driven. The residuals of the individual position points served as a measurement of the deviation from the target tramline. **Utilisation of vehicle working width** was calculated on the basis of the tilled field or bed widths, whilst vehicle working widths were calculated according to manufacturer's instructions and number of tramlines travelled.
For statistical analysis TIBCO Spotfire S+® 8.1 for Windows (TIBCO Software Inc., Palo Alto, California, USA) was used with fixed-effects ANOVA. Values of 14 different drivers were analysed: 7 for primary tillage, 3 for seedbed preparation, and 4 for sowing. Since driver, field shape, etc. strongly influenced the measurement parameters and not all drivers drove all vehicles for all operations, values were pooled based on the drivers and were not split up into operations. This yielded a randomised design with the fixed factors 'Driver' and 'Driving with/without guidance system' and the dependent variables 'Driving Speed', 'Turning time', 'Steering Accuracy', 'Utilisation of Vehicle Working Width' and 'Heart Rate'.
The boxplot illustration used in the figures contains as lower and upper whiskers the minimum and maximum values, as box the lower quartile, median and upper quartile and as black rectangular dot the mean value, if applicable.

3. RESULTS

The differences in **driving speed** (main area: 4.1-11.0 km/h; headland: 4.8-12.6 km/h) could be explained by differences in tillage equipment, working depths, soils, drivers, and tractor performance. Drivers achieved on average more or less identical speeds both without and with a guidance system; there were no significant differences (Figure 1, left). The greater margin of fluctuation in the headland is presumably attributable to the effects of field shape and differences in the lifting processes of the implements.

Three hundred fifty turning operations by six drivers were used to calculate the **turning times** (Figure 1, right). The average turning times without and with guidance system were 30 and 29 s, respectively. Differences were not significant. The in-some-cases high maximum values were attributable to factors to do with the natural landscape at the field margin, which extended the turning distance.

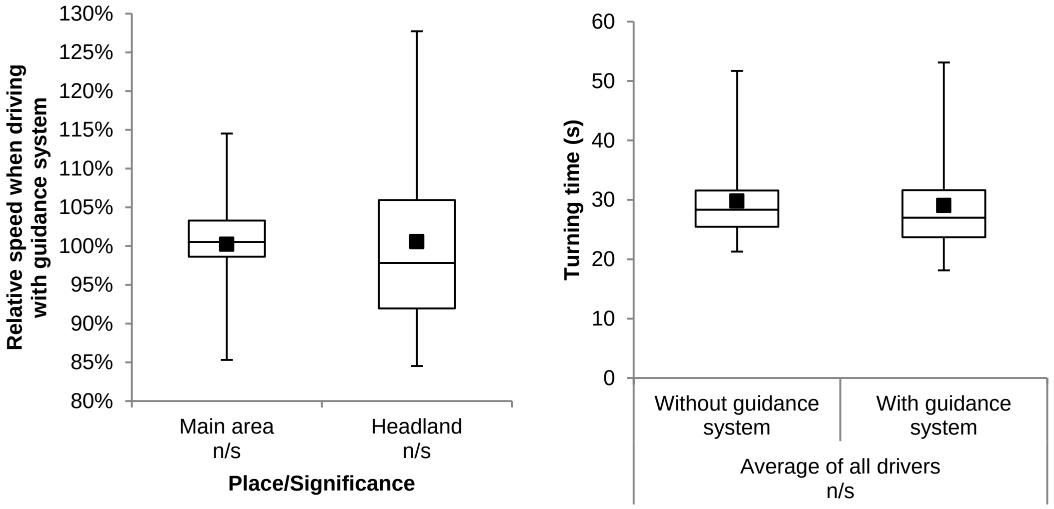

Figure 1, left: Relative speed when driving with guidance system, statistically analysed across all drivers. Speed without guidance system is 100%. Differences are not significant in either the main area or the headland. Right: Turning times of a total of 350 turning operations with 6 drivers. Turning times with/without a guidance system did not differ significantly on average. n/s = not significant

Two hundred one individual tramlines in the main area made by five drivers in spring 2011 were used to analyse **steering accuracy**. In the case of primary tillage and seedbed preparation, drivers steered more accurately with a guidance system than without. Accuracy rose along with increasing working width. For sowing without guidance system, the two drivers with track markers drove with a similar accuracy to those with a guidance system, or in a similar accuracy range to the drivers using a guidance system for primary tillage and seedbed preparation. The boxplot in Figure 2 on the left side shows that the regression residuals used as a measure of steering accuracy decreased statistically significantly with a guidance system. The standard deviation of the regression residuals fell from 0.31 m without to 0.12 m with guidance system.
The boxplot in Figure 2 on the right side shows the **utilisation of vehicle working width** based on the data from six drivers and an average vehicle working width of

8.5 m. With a median of 99.1 % without and 99.8 % with guidance system, utilisation is very high in both instances. Without a guidance system, the driver usually drives with a slight overlap; with a guidance system, there are also skips. Based on the average vehicle working width of 8.5 m, the working width utilisation with a guidance system is 0.04 m higher than without guidance system. Differences were not statistically significant.

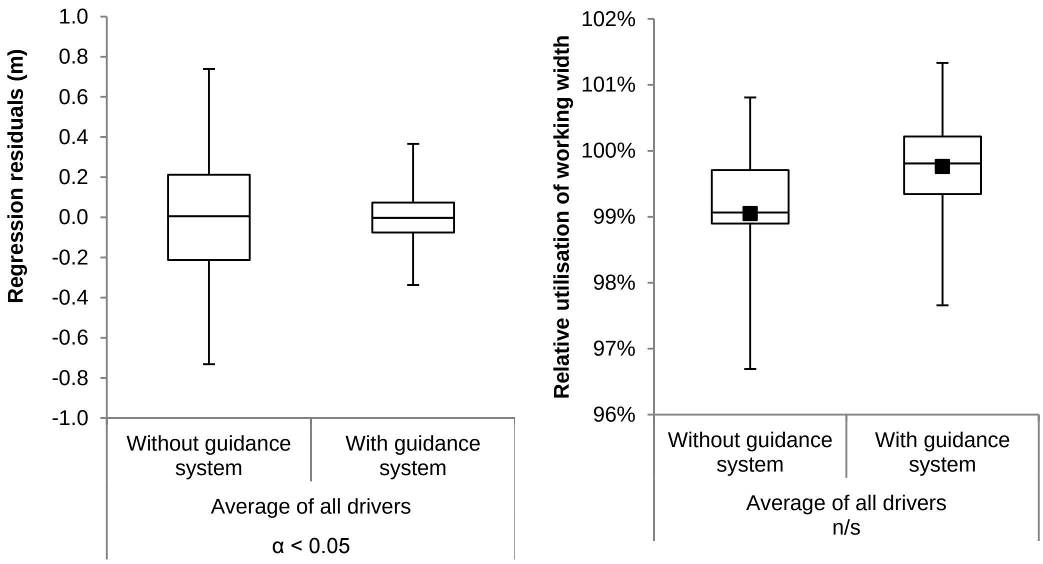

Figure 2, left: Steering accuracy when driving without/with guidance system as a boxplot of the regression residuals, i.e. deviation of the position points from the straight line of regression adopted as a target tramline. On average, differences were statistically significant. Right: Relative utilisation of vehicle working width in percent. Less than 100 % means an overlap, more than 100 % a skip. Differences were not significant.
α < 0.05 = significant difference, n/s = not significant

Heart-rate averages ranged between 64 und 99 min^{-1}, the minimum and maximum values between 48 and 167 min^{-1}. Average heart rate was 84 min^{-1} in the main area and 86 min^{-1} in the headland. In both the main area and the headland, heart rates were in only a very few cases higher, remained at the same level for a few drivers, and were lower for the majority of drivers with as opposed to without a guidance system. No trend towards a dependence of the operations was identified. Heart rate in the main area and headland fell on average by 2 min^{-1} or 2 %, with differences being significant in each case (Figure 3). With a median of 97.5 %, relief in the headland was higher than in the main area, where the figure was 98.5 %.

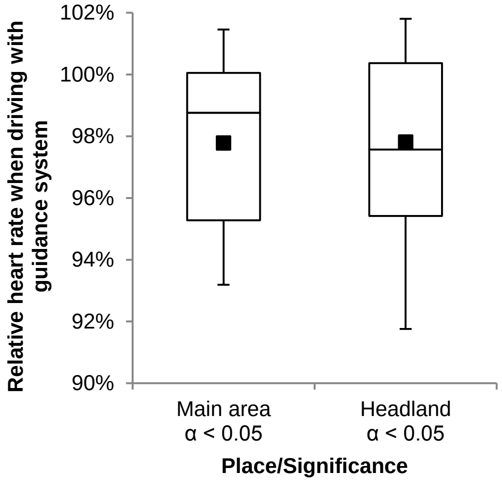

Figure 3: Relative heart rate when driving with guidance system, statistically evaluated across all drivers. Driving without guidance system = 100 %. Driving with guidance system leads to significantly lower heart rates. $\alpha < 0.05$ = significant difference

4. DISCUSSION

The use of a guidance system had a minimal impact on **driving speed**; given the large fields and working widths, other factors seemed to have been decisive here. The almost identical driving speeds in the field with and without a guidance system are presumably attributable to the fact that, regardless of whether or not a guidance system was used, drivers always attempted to drive at the maximum possible speed for the operation in question. Controlling connection accuracy did not have a limiting effect. In literature no information on the impact of guidance systems on driving speeds was found.

The marginally lower **turning times** measured with a guidance system can presumably be attributed to the fact that omega curves and skipped tramlines were used as turning modes. In terms of time requirement, these two turning modes differ substantially less than a time-consuming swallowtail-shape turn, which was never performed in the trial with the large working widths and surface areas. Significant differences are to be expected when, given a small working width, the swallowtail turn can be avoided by skipping the tramlines (Demmel, 2007; Moitzi, Heine, Refenner, Paar, & Boxberger, 2007).

With regard to **steering accuracy**, measurements showed that higher accuracies were in general achieved with rather than without guidance systems. Measurements found in the literature showed that higher steering accuracy is achieved with a guidance system. This tallies well with the current findings (Amiama-Ares, Bueno-Lema, Alvarez-Lopez, & Riveiro-Valiño, 2011; Berning, 2011; Gomez-Gil, San-Jose-Gonzalez, Nicolas-Alonso, & Alonso-Garcia, 2011; Kroulik et al., 2009; Macak & Nozdrovicky, 2011).

In the present trials, the **utilisation of vehicle working widths** was increased by an average of 0.04 m via the use of guidance systems. This is less than in the literature, which reports a 0.06-0.15 m improvement in utilisation (Berning, 2011; Keller, 2005).

For working widths between 6-15 m, 0.04 m seems relatively low, and the utilisation without a guidance system seems very high. The results should be attributable to the fact that the work was done on large-scale farms by professional drivers who achieved a very high working-width utilisation even without a guidance system.
The major differences in **heart rate** between the drivers are primarily attributable to their individual dispositions, and secondarily to the different requirements for operating the technology while driving. The average 2 min^{-1} reduction in heart rate when driving with a guidance system matches the heart-rate changes of 1-2 min^{-1} mentioned in the literature during adaptation to simple changes of situation in street traffic (De Waard, 1996) and the slight difference between positioning for parking and waiting for the automatic parking operation (Reimer, Mehler, & Coughlin, 2010). Although the measured differences seem low, it must be borne in mind that guidance systems scarcely change the degree of physical exertion, and that heart rate thus primarily indicates the change in mental strain. At two beats per minute, they correspond to the measured difference in heart rate between driving in the main area and in the headland. In other words, guidance systems can reduce the strain to an extent that can be compared to the difference in strain between headland and main area.

When interpreting the results of the study some limitations should be borne in mind: For organisational reasons it was neither possible to measure the same driver at different tasks, nor to carry out long-term measurements over full working days or during full day- and night shifts. Observation periods were between 1.1 and 2.8 hours per driver. Statements with respect to the effects of guidance systems in the case of longer driving times or different concentration and visibility conditions during the day and at night are therefore only possible to a limited extent. With longer deployment, driving performance and ergonomic effects might differ. It may be presumed that steering accuracy and utilisation of vehicle working width in particular would tend to decrease with a longer working time, poor visibility conditions and at night-time, but that it would nonetheless be possible to work consistently accurately with a guidance system. It can also not be ruled out that the drivers studied may have behaved differently in the observed situation, e.g. may have driven with greater concentration, thereby achieving a better quality of work than would have been the case in the everyday situation.

5. CONCLUSION

In the present 17-driver study investigating the operations of primary tillage, seedbed preparation and sowing, the guidance-system effects measured were for the most part slight. Driving speeds in the headland and in the main area, turning times and utilisation of vehicle working widths were in some cases slightly more advantageous with a guidance system than without, but did not differ significantly from one another. Working widths, driver, and factors to do with the natural landscape – such as field shape and optimal turning strategies resulting therefrom – had a substantially greater influence in the practical trial on the measurement parameters than did the use of a guidance system. With the use of guidance systems, steering accuracy increased statistically significantly. The statistically significant effect of a slight heart rate reduction of the drivers demonstrates that the comfort and ergonomics of tractor jobs may increase with the use of guidance systems. Drivers may remain efficient for longer, and quality of work may remain at a consistently high level.

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